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Central and Eastern Europe Climate Change Impact and Vulnerability Assessment

Specific targeted research project

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D6.1: Crop yield and forest tree growth changes influenced by climate change effects, regional conditions and management systems

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Introduction

Central Europe is located between East and South European climate change hot-spots where the climate change impacts are thought to become visible sooner or will be more pronounced or both (Giorgi, 2006). Agriculture still constitutes an essential part of economy, and of the landscape. In many cases it specializes on production of selected crops (e.g. spring barley) that are then utilized for valued commodities. Thus the effect of future climate change on this activity is rather important not least because the agriculture is naturally one of the most weather-dependent human activities. In order to study the potential impact of climate change three areas of research has to be addressed, as they are essential for estimating future climate change impacts:

1) The effect of climate change on the future drought frequencies;
2) The effect of climate change (including the effect of higher ambient CO_2) concentration on the crop growth and productivity of key crops;
3) The future infestation risks posed by agricultural pests and diseases.

Climate also strongly influences majority of processes in forest ecosystems, and forests (and the wood chain) influence a large part of the anthropogenic forcing factors (carbon, methane, nitrogen cycles, albedo, atmospheric solid particles, biomass burning etc.). Any changes in climatic conditions are expected to result in response at all levels – from biomes through communities and species to individuals (Hansen et al. 2001). Based on the former studies (e.g. Prentice et al. 1993; Sykes et al. 1996; Lindner et al. 1996; Lexer et al. 2000), we can expect significant changes and shifts of the potential distribution ranges of species leading in changes of structure and composition of forests in many areas. The climate change will affect also the biomass productivity (Linder et al. 2000; Lasch et al. 2002) and disturbance regime (mostly increase of disturbance frequency and intensity) in forest stands (Cannon 1998; Dale et al. 2001; Ayres and Lombardero 2000; Rebetz and Dobbertin 2004; Woods et al. 2005). The main problem is, climate changes are too fast to allow for spontaneous changes in forested areas, especially at the lower limits of distribution ranges. Recently, also the problem of biological invasion become recognized as another important agent of global change (Vitousek et al. 2006, Simberloff et al. 2000).

A region where anticipated changes might hit especially seriously is the eastern-continental part of Central Europe. The reason lies first of all in the fact that this region reaches “down” until the xeric distribution limits of ecosystem-dominating species and even to the actual limits of closed forests as well. Increased drought frequency means therefore not only loss of diversity, but might also lead to loss of closed forest cover, with deep ecological, economic, environmental and aesthetical consequences. The following key areas of climate change impacts on forest ecosystems are addressed in the report:

1) The effect of climate change on the growth of key forest tree species
2) The effect of climate change on future dynamics of key forest tree pests

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AGRICULTURE

Authors:

Miroslav Trnka, Martin Dubrovský, Zdeněk Žalud, Daniela Semerádová, Petr Hlavinka, Eva Kocmánková, Pavel Kapler **(CZ)**

Josef Eitzinger, Sabina Thaler **(AU)**

Elena Mateescu, Vasile Turcu, Oana Oprea **(RO)**

Vesselin Alexandov **(BG)**

Bernard Šiška, Peter Samuhel, Jozef Takáč **(SK)**

Methods and models

Drought indices

Numerous drought indices have been developed to characterise the drought (see, e.g., Keyantash and Dracup, 2002; Heim, 2002 for the reviews). Of these, the most common indices used worldwide include *Standardized Precipitation Index* (SPI; developed by McKee et al., 1993) and *Palmer Drought Severity Index* [PDSI, developed by Palmer (1965); complete descriptions of the equations can be found also in Alley (1984)].

The values of SPI and PDSI may be converted into drought categories which express the drought severity with respect to the normal conditions in the given site. For SPI, the categories span from extremely dry (SPI≤−2) to extremely wet (SPI≥2) with normal being with (-1,+1) (http://www.drought.unl.edu/whatis/indices.htm). For PDSI, the categories go from extreme drought (PDSI≤−4) to extremely wet (PDSI≥4) with near normal conditions being indicated by PDSI ∈ (−0.5,+0.5> (http://www.drought.unl.edu/whatis/indices.htm).

The two most common drought indices, SPI and PDSI, are modified here in a way to make them applicable in the climate change impact study. These indices, however, might be used also in the between-station comparisons making them potentially useful in spatial analysis of drough conditions. To assess future-climate drought condition, the drough indices are derived from the weather series obtained by modification of the observed series according to 5 GCM-based climate change scenarios (CSIRO-Mk2, CGCM2, GFDL-R30, HadCM3, CCSR/NIES) and SRES A2.

In the case of the classical SPI, its values are calculated from the precipitation series, which is identical to the series used to derive parameters of the precipitation sums. As a result, the quantiles of the SPI are always about the same for each input weather series and cannot be used for between-station comparisons, nor for between-period (e.g. essential in assessing the potential impacts of climate change) comparisons. A similar situation applies when using the PDSI when the values are derived from the same series as was used to calibrate the underlying model resulting in PDSI values having similar distributions for all input weather series (representing various stations and/or various periods). Hereafter, we shall call these indices the *self-calibrated indices*.

In this overview, we introduce the *relative indices* (rSPI and rPDSI), which might be used for both types of the comparative studies: either to compare drought conditions at different sites during a given period or to compare drought conditions for a single site but during different periods. The relative indices differ from the self-calibrated indices by using the reference ("learning") series (precipitation series for SPI; precipitation plus temperature series for PDSI) as a first step in calibrating the models used for calculating the values of the indices. The learning series may either be a reference station (when comparing two stations), or the reference period (when comparing drought conditions in different periods). Having calibrated the model, it is then applied to the series, which relates either to the different station and/or to the different period. Alternatively, we use the learning series created by aggregating data from a set of stations. In this case, the resultant learning series represents a wider spectrum of precipitation-temperature situations, which should make the model applicable for a wider spectrum of climatic conditions.

The executable models for the relative indices were obtained by modifying the original self-calibrated indices available from the University of Nebraska—Lincoln (Computer Science and Engineering, and National Drought Mitigation Center). The original version of the PDSI is described in Wells et al. (2004).

The effect of the climate change on selected crop pests

Predicting the potential distribution of agricultural pests, both indigenous and introduced, plays a key role in determining the impact of global change on agricultural, horticultural, and forestry ecosystems (e.g. Beaumont *et al.*, 2005 or Gray, 2004). In this overview of the project results we will focus only on one of the most important corn (*Zea mays* L.) pests, the European corn borer (*Ostrinia nubilalis* Hubner). It was chosen because of its nearly global presence, adaptation potential, and its expected sensitivity to climate change within regions of Central Europe. The European corn borer (ECB) population is presently univoltine in most of Central Europe. In the southeast USA, it produces up to four generations per year (Mason *et al.,* 1996), and up to six generation per year are possible under favorable conditons. The areas with two or more generations per season suffer much higher economical losses, since the later generations of larvae tunnel through stalks, ear shanks, and husks. This type of damage causes disruptions of assimilate translocation throughout the plant, introduction of pathogens (Keszthelyi and Lengyel, 2003), and increased plant lodging (Mason *et al.*, 1996). Presently, the only Central European region with bivoltine populations is in Hungary (Keszthelyi and Lengyel, 2003) due to its favorable climatic conditions and host availability during most of the seasons. This situation could be altered if the climate conditions would permit the development of the full second generation in the presently monovoltine areas.

In order to study the potential risks, a multigenerational phenology model that accommodates known influences of climate conditions on the ECB population was developed and evaluated (Fig. 5). We will focus further on the effect of climate change on the size of the climatically suitable area for ECB univoltine and bivoltine populations under the expected climatic conditions using 5 GCM models and range of SRES scenarios including A2, A1T and B1 with various climate system sensitivities. The study results were generalized in form of maps based on the simulations carried out for 45 individual sites where weather data were available (Fig. 2a).

DSSAT – CERES

The IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) project has developed a computerized decision support system DSSAT (Fig. 2.12) that integrates soil, weather and crop databases with dynamic crop simulation models (IBSNAT, 1993; Tsuji et al., 1994). System analysis and validated crop simulation models provide an alternative method for representing agricultural production (Tsuji et al., 1998). Using this type of models the dynamics of crop growth and development can be evaluated under a wide range of management scenarios and environmental conditions. The application of the crop models for the assessment of climate change impacts on agricultural production and potential of agrotechnological adaptation are one of the effective applications of crop models (Thornton and Hoogenboom, 1994).

The CERES generic grain cereal and CROP grain legume models of the DSSAT (Tsuji et al., 1998) were widely used used to determine the vulnerability of current agricultural management under future climate change scenarios across USA, Europe and Asia. These crop models are designed to be used with a minimum set of soil, weather, genetic and management information. The models are based on daily time step and thus require daily inputs of weather data, consisting of maximum and minimum temperature, solar radiation and precipitation sums. They calculate crop phenological and morphological development using temperature, daylength, genetic characteristics and vernalization requirements, where appropriate. Leaf expansion, leaf growth and plant population provide information for determining the amount of light intercepted, which is assumed to be proportional to biomass production. The biomass is partitioned into various growing organs in the plant using a priority system. A water and nitrogen balance submodel provides feedback that influences various growth and development processes. An improved soil water model was implemented recently, which contains better description of infiltration, redistribution and root uptake. Restrictions to percolation are included in soil inputs so that perched water tables can be simulated along with oxygen stress effects on root and crop growth processes. An option has been added to compute potential evapotranspiration using the Penman equation, which uses humidity and wind speed as input if these data are available (Hoogenboom et al., 1999; Tsuji et al., 1994). The DSSAT seasonal analysis program (Thornton and Hoogenboom, 1994) was used to simulate possible adaptation measures, which can decrease the potential agricultural crop vulnerability under expected climate change conditions.

In order to explore the effect of climate change on cereal production three crop models are considered for the future use i.e. CERES-Barley, CERES-Wheat and CERES-Maize. Process of selection of the appropriate and well performing crop model was part of the preceding study (Eitzinger *et al.*, 2004). Based on the multiple criteria analysis including experimental evaluation of the soil water and evapotranspiration routines using lysimeter data the model CERES (Hoogenboom *et al.,* 1994) was selected from range of models including (WOFOST. SWAP and STICS). The model algorithm for incorporation CO_2 effect was also thoroughly tested (e.g. Tubiello *et al.*, 1999). This particular group of crop models belongs to the most frequently used tools in recent years in the climate change studies (Tubiello and Ewert, 2002). Results of the study might therefore help in interpretation of the previously conducted climate change impact studies using this model as well as in proposing methodologies for further undertakings on this field of research. Previously conducted studies also proved that the model performs well in various environments (e.g. Wolf *et al.*, 1998; Travasso and Magrin, 1998). The used model is of the mechanistic/dynamic variety and operates within the Decision Support System for Agrotechnology Transfer ´DSSAT´ (Tsuji *et al.*, 1994).

DAISY

DAISY is a comprehensive and deterministic one-dimensional model for simulation of crop production, soil water dynamics and nitrogen dynamics in crop production at various agricultural management practices and strategies. The particular processes considered include transformation and transport processes involving water, heat, nitrogen and carbon. Model simulates the parts of the water, nitrogen and carbon cycles that are related to agricultural systems (Hansen et al., 1990; Hansen, 2000; Abrahamsen and Hansen, 2000).

The hydrological model component comprises a surface water balance and a soil water balance. The atmosphere and the ground water constitute the boundary conditions of the considered system. The potential evapotranspiration forms the upper limit for the evaporation and transpiration processes. The hydrological processes considered in the model include submodels for snow accumulation and melting, interception, through-fall, evaporation in the crop canopy, infiltration, surface runoff, water flow in the soil matrix as well as in macropores, water uptake by plants and drainage to pipe drain. The vertical movement of the water in the soil profile is modelled by means of a numerical solution of the Richards equation. Water uptake by plant roots is based on a solution of the differential equation for radial water flow to the root surfaces and plant root density in the soil profile (Abrahamsen 2006, Hansen et al., 1990; Hansen, 2000; Abrahamsen and Hansen, 2000).

The heat balance model simulates soil temperature as well as freezing and melting in the soil.

The simulation of the organic matter balance and the nitrogen dynamics is interconnected and the organic matter component is an integral part of the nitrogen balance model. The model considers three types of organic matter: soil organic matter (SOM), soil microbial biomass (SMB) and added organic matter (AOM). Nitrogen is in the model system present as ammonium, nitrate and organic matter nitrogen. The solute balance model simulates transport, sorption and transformation processes including mineralisation, immobilisation, nitrification, denitrification, sorption of ammonium, uptake of notrate and ammonium as well as leaching of nitrate and ammonium. The actual plant mineral nitrogen uptake by the plant is determined either by the plants‘ nitrogen demand or the availability of the mineral nitrogen in the rooting zone.

The crop model is the most complex model in DAISY. The considered plant compartments are root, leaves, stems and storage organs. The crop model simulates plant growth and development including photosynthesis, respiration, the accumulation of dry matter and nitrogen in different plant parts, the development of the leaf area index (LAI), the distribution of roots and stress factors. Water stress occurs when the water uptake is less than the potential transpiration and nitrogen stress occurs when the nitrogen concentration in the crop is below a certain threshold (Hansen et al., 1990; Hansen, 2000; Abrahamsen and Hansen, 2000).

The management model can be considered a programming language that allows for building complex management scenarios. The management is just a list of actions performed at a predefined date. The management model comprises two different language elements: direct management action and conditional statement. The conditional statement allows governing the execution of the management action only when certain condition is fulfilled.

DAISY can use weather data at different time scales. The most detailed simulations require hourly values of global radiation, air temperature, relative humidity, wind speed and precipitation. The minimum weather data requirement is daily values of global radiation, air temperature and precipitation.

The minimum soil data required to describe soil horizon is texture, organic matter content, soil organic matter fractions, C/N-ratio and hydraulic properties (Hansen et al., 1990; Hansen, 2000; Abrahamsen and Hansen, 2000).

Newhall soil moisture model

The Enhanced Newhall Simulation Model (ENSM) enables to model the annual soil moisture regime (by USDA soil classification) and allows exploring of frequency and probability of appearing that soil moisture regime events. The soil profile is described in terms of the maximum water holding capacity of the root zone (MWHC). The essential inputs for identification of soil moisture regime include monthly potential evapotranspiration (PET), precipitation, daily soil water content in predefined soil layers and soil temperature in 50 cm depth (T_50). For estimating PET and daily soil water content of soil we used the FAO Water Balance Model. It was validated by using dataset 1998-2005 from the lysimetric station in Gross-Enzersdorf, Austria. Validation included 8 seasons at three common soil types: typical chernosem, sandy chernosem and fluvisoil; comparison of observed (TDR) and simulated (FAO) soil moisture and yielded satisfactory results. The key importance for the correct classification of soil climate regime by NSM has the value of quantity of „wet days“ during each year (expressed by MCSyearWD parameter). For it's validation we used the same dataset as for FAO model and period 1999-2004 and the validation was successful. Moreover the soil regime classification is a question of long term water balance rather than daily or monthly values and we are certain that the long-term means are well reproduced. This has been shown for all three soil types tested (Kapler *et al.* 2006).

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Model regions and climate change impact analysis - the Czech republic

In the case of the Czech Republic the agricultural land covers over 54% of the country area that by and large composes of the arable land (72%). The most dominant crops grown in the Czech Republic (as far as acreage is concerned) as well as in whole Europe are cereals that cover 54% of arable land (or 21% of the total country area). The single most important crop in this region is winter wheat that accounts for 54% of the cereal acreage and spring barley with almost 20%, followed by range of other crops including winter oil seed rape, potatoes, sugar beet, maize and forage crops.

Experimental sites

The crop models CERES-Barley and CERES-Wheat (v. 3.5) were calibrated at 4 and 2 sites respectively across the study area (Fig. 1) that were characterized by significant altitudinal range (176 and 540 m a.s.l.) and rather representative climatic conditions for the spring barley and winter wheat production in the Czech Republic (mean annual temperature from 6.8 to 9.6 °C and mean annual sum of precipitation between: 461 and 575 mm). Following the calibration the model performance was verified by independent data set at 13 (5) other experimental sites (Fig. 1). Their altitude ranged from 190 to 650 m a.s.l. with mean annual temperatures between 6.2 and 9.3°C. The mean annual precipitation range was from 439 mm at the driest site to 738 mm at the highland areas. In case of the European Corn Borer simulation database of 20 monitoring sites of the State Phytosanitary Administration were taken into account and over reports from 234 individual sites during 1961-2003 were included. The spatial assessment of spring barley and winter wheat production under the present and changed conditions was carried out at 1 sq. km resolution and using combination of more than 1500 continuous soil polygons (described by 394 soil profiles) combined with daily data from 125 weather stations. In case of the Soil Moisture Regime and European Corn Borer population a smaller but still representative subset (i.e. 45 stations) was used.

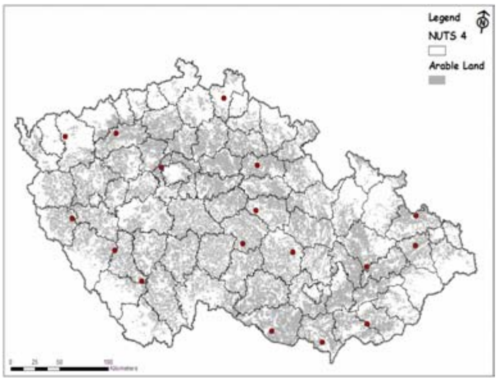


Fig. 1. Geographical location of the experimental sites.

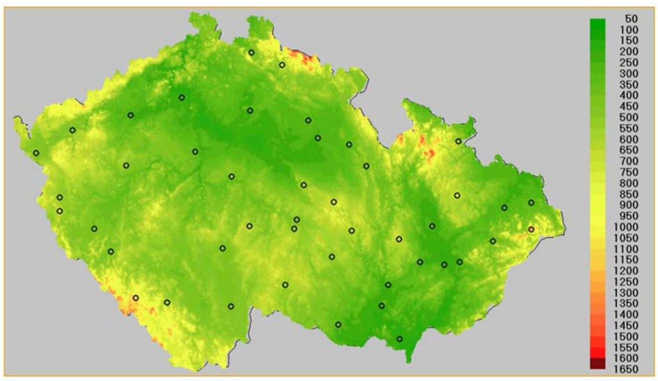


Figure 2: The spatial distribution of 45 meteorological stations used as the source of weather data in the presented study and presentation of altitude data available in the Digital Landscape Model.

The effect of climate change on the future drought frequencies over the territory

In assessing impact of the forthcoming climate change on the drought conditions in the 45 stations, the characteristics of the drought indices derived from the future climate monthly weather series (obtained by the direct modification of the present observed series) are compared with those derived from the station observational monthly weather series. As SPI is based only on precipitation, the changes in SPI-01 and SPI-12 closely follow the precipitation changes prescribed by the climate change scenarios. For example, projected increase in winter precipitation implies increase in relative SPI-01 with decreasing frequency of SPI-based dry months. Conversely, decrease in summer precipitation implies decrease in relative SPI-01 with increasing frequency of SPI-based dry months. For a whole year, slight changes in annual precipitation sum imply slight changes in the annual SPI characteristics.

In contrast with SPI, the changes in PDSI are due to changes in both precipitation and temperature. The drought risk indicated by mean value of PDSI will significantly increase both in winter and summer under each of the five GCM-based scenarios. In summer, the drought risk increase due to precipitation decrease will be augmented by the temperature rise. In winter, the effects of the temperature rise and decreasing precipitation will act in opposite directions but the effect of the temperature rise will dominate. Due to the great persistence of the drought index with no apparent annual cycle being involved, the difference between the summer and winter changes is only small. The most significant effect of the climate change on PDSI values is in case of the CCSR/NIES scenario which exhibits most significant temperature rise.For example, in summer under CCSR/NIES scenario nearly 70% of stations may encounter drier (in terms of mean value PDSI) conditions compared to the driest station in the present climate. This shift is, however, lower in other GCMs (due to lower temperature increase) as well as in the case of SPI index which is affected only by precipitation changes. In summer, the shift in SPI is large but the shift in winter is oposite (towards wetter conditions) so that the shift in annual mean of both SPI-01 and SPI-12 is very small. These results may suggest, that the vegetation season will be negatively affected by more frequent summer droughts whilst the increased winter precipitation might increase risk of floods. Another approach to assessing the effect of the prognosed climate change on the drought risk is displayed in Fig. 3.

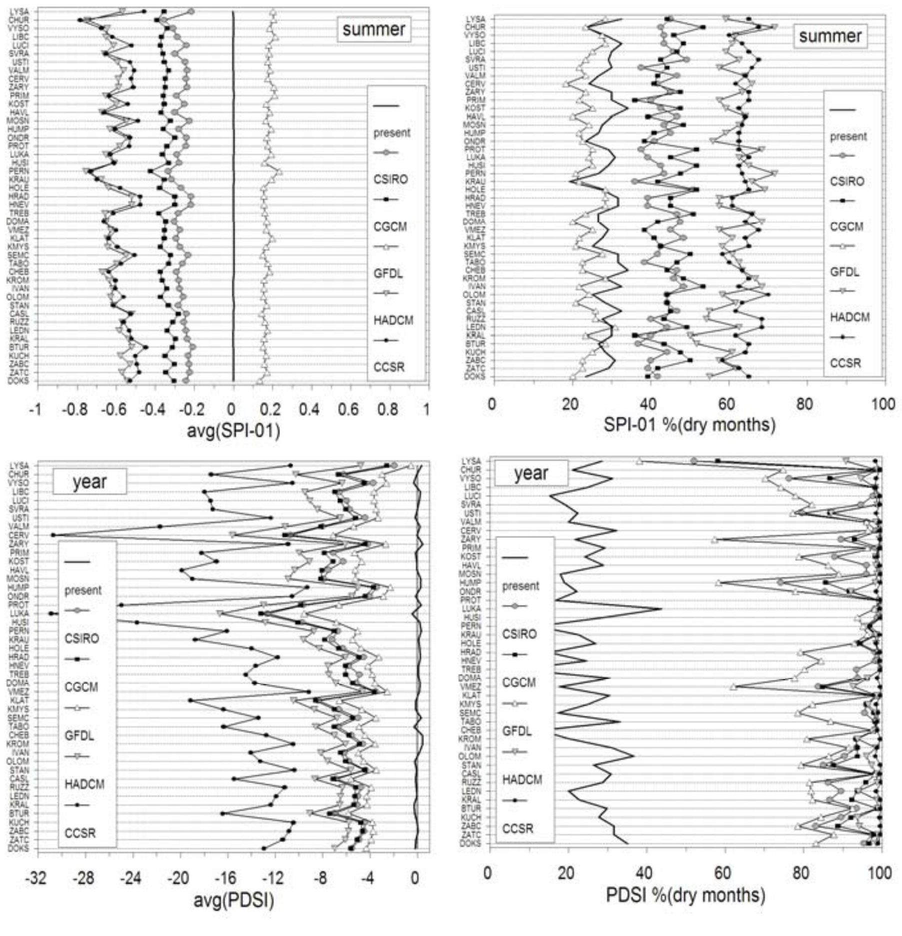


Figure 3 Left: Average value of the relative SPI-01 (top: winter; middle: summer) and annual PDSI (bottom) for the changed climate; the indices were calibrated with the weather series observed in the given station.. Right: percentage of months within the drought periods.

In contrast with the previous experiments, where the indices for each station were calibrated with observational data aggregated from all stations, the drought indices are now calibrated using a given station data and then applied on the future-climate weather series obtained by modification of the observational data according to the climate change scenario. The figure thus compares the future-climate relative SPI-01 and PDSI in terms of the present-climate PDSI and SPI-01 conditions. The left panels show average values of the two indices, the right panels show how the number of drought months will increse under climate change. While the average values of the self-calibrated indices are close to zero (the between-stations differences in the average values of the two drought indices are not considered to be significantly different from zero), which is a consequence of the self-calibrating procedure, the average values of the future-climate drought indices show that a) PDSI values will be much lower (under all climate change scenarios) resulting in a large increase in the drought months occurrence. Percentage of the months being within the drough spells will approach 100%. b) Average SPI-01 values will rise in winter by 0.04 (GFDL scenario) to 0.6 (CCSR scenario) as a consequence of the precipitation increase during this season resulting in decrease of drought months occurrence by few (GFDL scenario) to approximately 50% (CCSR scenario). c) In summer, SPI-01 will decrease in most scenarios (all except for the GFDL-based scenario) as a consequence of the precipitation decrease. The decrease of SPI values will result to increse in the drought months which will be more then doubled under HADCM and CCSR scenarios.

Soil climate change as assessed by Newhall soil moisture model

The main input for NSM is potencial evapotranspiration value for the specified soil layers. This key value was obtained through the FAO – Crop Water Balance Model, which was combined with a simple snowpack model to account for specific winter conditions. The method was evaluated on three most productive and in agricultural landscapes frequently apperaring soil types: deep grounded chernosem, sandy chernosem and black wet soil. Evaluation dataset was provided by lysimeters of Federal Office and Research Centre for Agriculture in Vienna, Austria. To allow for spatial analysis of the soil climate the NSM was run at 45 weather stations where daily temperature, wind, relative humidity, global solar radiation and precipitation sums for the period 1961-2000 were available (Fig. 2). Four major groups of soil conditions according to their maximum soil water holding capacities were taken into account. In the next step the model was run over the climatic data corresponding to the conditions expected under future climatic conditions taking into account 5 GCM-based climate change scenarios (CSIRO-Mk2, CGCM2, GFDL-R30, HadCM3, CCSR/NIES) and assuming A2 and B1-SRES emission scenario for time slices of 2025, 2050 and 2100.

It has been found that under the present climate only a fraction of the territory is situated within the drought risk area with dry tempudic soil moisture regime (Fig. 4). Drought risk area is confined only to well known dry region of the country i.e. South Moravia. Under the changing climate a notable gradual increase of the areas with a high probability of dry events was noted. When the model was run with data accommodating for increase of greenhouse gases emissions according to A2-SRES, the shifts in the soil climate characteristics were rather dramatic and took place within decades rather than centuries (Fig. 4). It is obvious that by the year 2100 the most of the Czech Republic arable land would be faced with relatively frequent wet tempustic soil moisture regime events accompanied also by higher probability of drought spells (Fig. 4). This type of the soil climate have not been recorded up to now at the territory and is in the same time accompanied by significant increase of soil temperature (especially towards the end of the century). As the aridization of the soil climate regimes is closely related to other drought impacts such as decrease of crop yields, damage to forest stands, low stream flow and reservoir levels or change etc., a significant increase of drought related economic and social economic losses is likely under the climate change conditions.

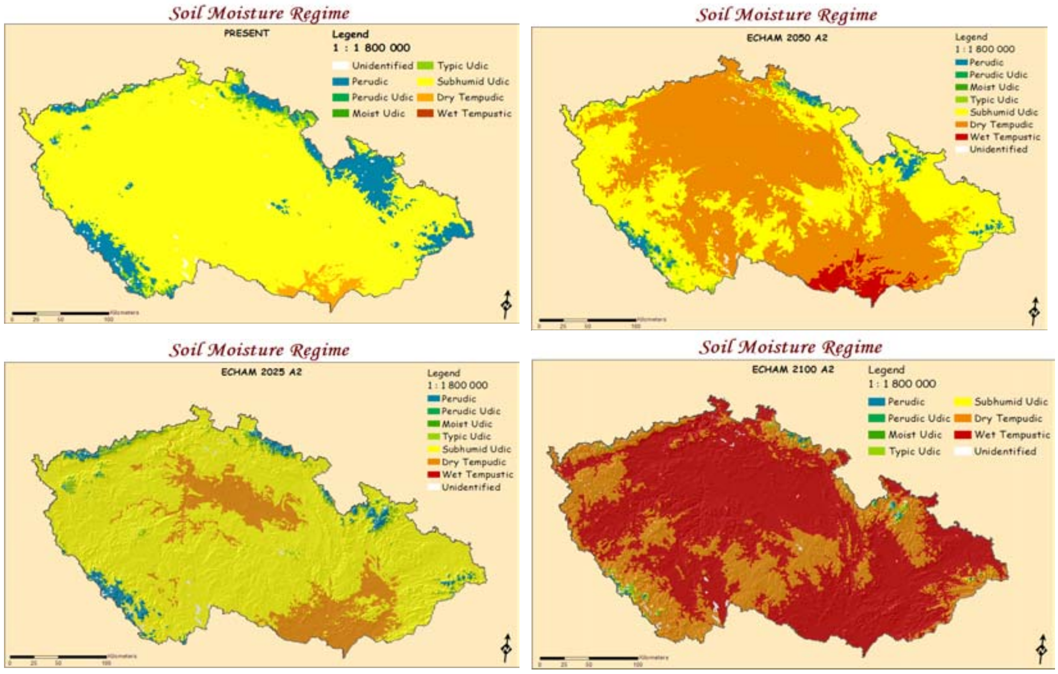
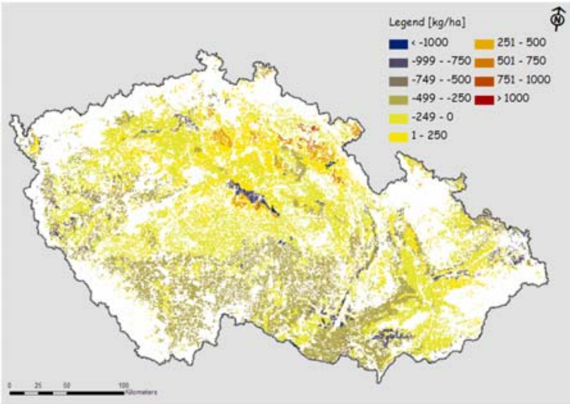


Fig. 4. Soil moisture regime under present and future climate conditions (ECHAM 4 – SRES A2 – High climate sensitivity).

The effect of climate change on the cereal crop production

Increase of the air temperature that is predicted by all scenarios would lead to the shortening of the vegetation duration of all three crops (interval from sowing till physiological maturity) and it is between 4-71 days in case of winter wheat. This is in accordance with the results reported by number of other studies (e.g. Harrison *et al.* 2000; Tubiello *et al.* 2000 or Alexandrov and Eitzinger, 2002). The magnitude of the change clearly depends to a large extend on the scenario used and the reference time period because the differences in the predicted temperature increase between the individual scenarios are great. The study confirmed that a significant shift in the duration of the vegetation season is to be expected by 2050-2100 (depending on the emission scenario used). The length of the cereal vegetation duration in the production areas with altitude over 600 m will equal to the present values in the Lowlands (300 m and less). The changes of the annual mean temperature expected according scenarios the HadCM-B1-2050 and the ECHAM-B1-2050 lie within interval 0.9-1.12°C. Such changes would then lead to shortening of the vegetation period by 2.3-3.5%. These findings correspond with the results of several field experiments (e.g. Wolf *et al.*, 1998) with winter wheat cultivar Minaret at Clermont Ferrand (France) and Rothamsted (England) in the temperature gradient tunnels. Increase of temperature during the grain filling period by 1.0°C lead to 2.6% shorter vegetation duration at Clermont Ferrand. The same temperature increment from sowing till maturity at Rothamsted caused the shortening of vegetation duration by 2.8%. With respect to the different parameters of the used cultivar, its different vernalization requirements and also differences in the day length between these two sites and Czech conditions it can be stated that the simulated results correspond well with these field trials.



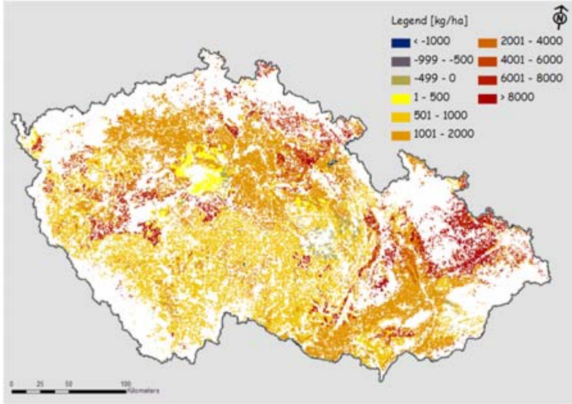


Fig. 5. Indirect effect of the climate change on the yield of the spring barley. The figure represents a reduction of the long-term yield means in 2050 (A2-HadCM3) compared to 1961-2000 yield levels.

Fig. 6. Combined effect (including CO_2) of the climate change on the yield of the spring barley. The figure represents a reduction of the long-term yield means in 2050 (A2-HadCM3) compared to 1961-2000 yield levels.

Impact of the changed weather conditions on the winter wheat yields (not including CO_2 fertilization effect) would lead to the yield depression, which would be the most severe in the Lowland and midland sites. Applying the ECHAM-A2-2050 and the HadCM-A2-2050 resulted in yield reduction reaching up to 25% (not shown). Generally the sites in the regions with presently low air temperatures would be the ones least affected by the indirect effect of climatic change (example of spring barley at Fig. 5). The main reason for the yield reduction lays in temperature increase that besides shortening of the vegetation duration through speeding up the developmental processes also influences the respiration rates as well as assimilate partitioning. Generally lower amount of precipitation during some months is not sufficient to cover the increased evapotranspiration demand caused not only by the higher temperatures but in some GCMs also by increased solar radiation sums. The results correspond with the overview of 17 experimental studies (Amthor, 2001) that were aimed on the investigation of the relationship of increased temperature and grain yield. Winter wheat reacted to the increased temperature sums (in range +1.1 – 4.0 °C) with yield reduction of 0.5.-48% in 16 (out of 17) cases. Already mentioned study with wheat Minaret cultivar (Wolf *et al.,* 1998) reported 11% yield depression per 1°C of increased temperature with only 3% standard deviation. Simulated results presented in this study show the yield reduction in interval 0-17% when scenarios the HadCM-B1-2050 and the ECHAM-B1-2050 were applied (estimated increase of annual mean temperature 0.9-1.2°C).

Combination of the changed climatic conditions and increased CO_2 concentration on crop yields would lead to the inverse trend in the grain yields. If the fertilizing effect is not included the wheat, barley and maize yields would reach 25-98% of the present values while when the stimulating effect is accounted for yields might increase by as much as 25% by 2100 in comparison with the present conditions. Despite differences between individual regions the trend seems to be positive across the whole Czech Republic (Fig. 6). The range of the change is few percents lower than the expected changes under similar climatic conditions reported e.g. by Izaurralde *et al.* (2003) or Olesen and Bindi (2002). The deviation could be easily explained by applying slightly different version of the GCMs and emission scenarios as well as by the specific conditions of the region. However the presented results contradict the former findings made within the framework of US country studies program that concluded that the winter wheat yield would decrease in the Czech Republic (Smith and Lazo, 2001). The difference was most likely caused by improper calibration of the CERES-Wheat model due to limited data and imperfect data sets. This finding demonstrates the necessity for critical overview of already reported results using better-calibrated models and state of the art methodology over the same study area. The effect of adaptation options will be explored in the follow up studies.

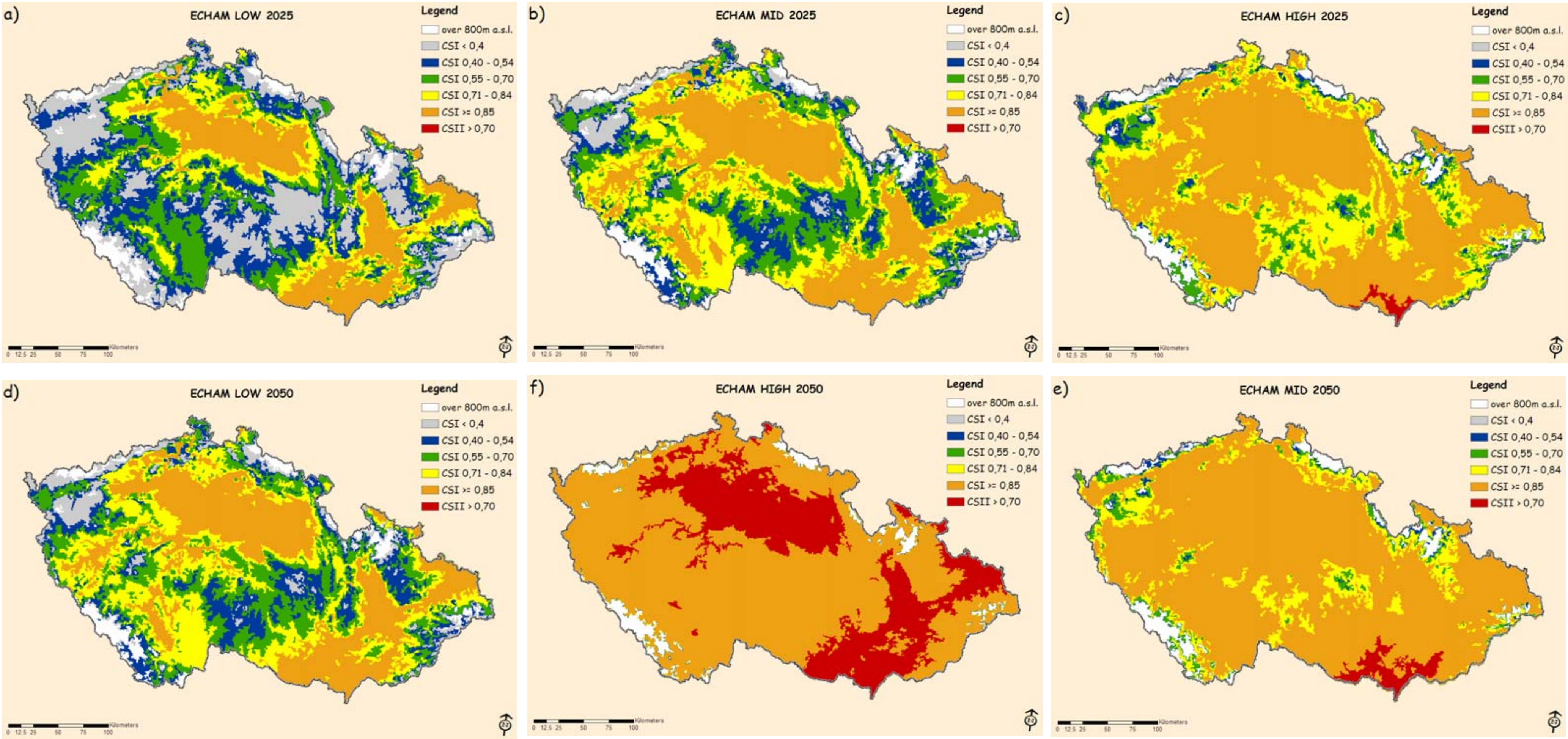


Fig. 7. Development of the climatically suitable areas for the 1st and 2nd generations expressed in terms of CS_I and CS_{II} during 2025 and 2050. The estimates are based on the ECHAM GCM model with a combination of the B1 SRES scenario and the low sensitivity of a climate system (ECHAM LOW), A1T SRES scenario and medium climate sensitivity (ECHAM MED) and A2 SRES scenario and high climate sensitivity (ECHAM HIGH)

The effect of the climate change on selected crop pests

The effect of climate change on the ECB climatic niche is profound and similar was found for other pests (e.g. Colorado Potato Beetle etc.). In most cases the climate change will lead to an earlier beginning of the growing season and will accelerate pest development. By 2025, the flight initiation could take place, on average, 4-10 days earlier than during the reference period, and the ECB life cycle will be completed 9-15 days earlier (Fig 8a).

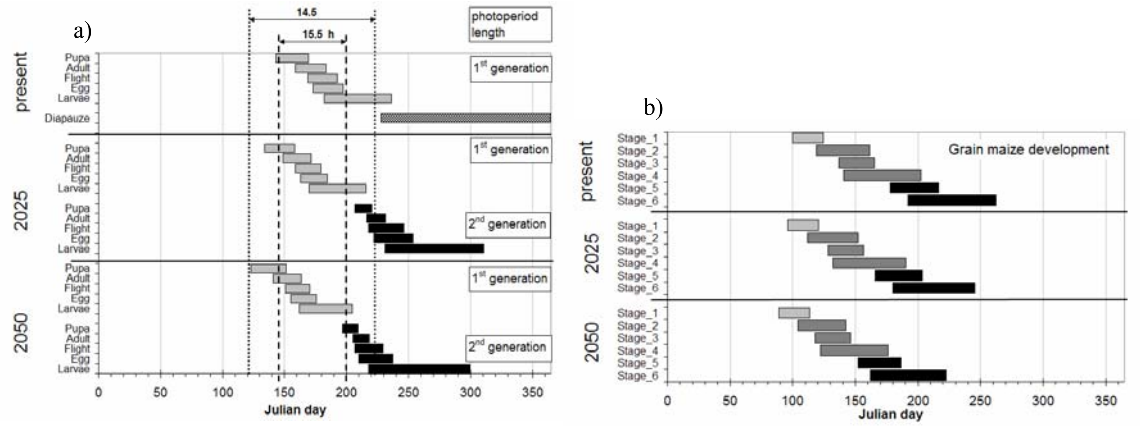


Fig. 8 a). Example of the life cycle of ECB under present climatic conditions and changed climatic conditions in 2025 and 2050 (A2 emission scenario, high climate sensitivity and ECHAM model) at the Lednice station (171 m a.s.l.; 16.83E; 48.78N). Each bar represents mean dates when individual stages are initiated and 95% of the population finished the given stage. The vertical lines delimit the period of the year with a day length (sunrise-sunset) of 14.5 to 15.5 hours respectively; b) Example sowing timing and the key developmental stages of grain maize at the Lednice station under present and changed climatic conditions estimated by the CERES-Maize model. Legend: (1) from sowing to emergence, (2) from emergence to the end of juvenile phase, (3) from the end of juvenile phase to the floral initiation, (4) from the floral initiation to the end of leaf growth, (5) from the end of leaf growth to the beginning of grain filling, and (6) the grain filling.

Differences exist between the scenarios, with some ECAMON runs predicting the completion of the first generation more than 1 month earlier by 2050, as compared to the reference period. Since it has been already shown for the example of the 1991-2000 period, the increase in air temperatures leads to a larger climate niche for ECB (Fig. 7a-f). This will be accompanied by a spread of the pest into these regions. A combination of B1 emission scenario, low climate sensitivity, and NCARPCM model assumes only a small temperature increase and an enlargement of the ECB prime niche area in 2010 by only a 4.0% compared to 1961-1990 period. According this scenario, the prime niche area would increase to 31.0 % of all arable land by 2025, and up to 43.0% by 2050. Such development is not probable, since the rate of green house gas emissions assumed by the SRES-B1 scenario is very low. The mid-range estimate (based on SRES-A1T emission scenario, medium climate sensitivity, and the HadCM model) would result in the expansion of ECB to 62% of arable land by 2025. Almost all agricultural land would allow for the existence of an univoltine ECB population by 205. If we consider the possibility of a rapidly progressing climatic change (i.e. SRES-A2 emission scenario, high climate sensitivity, and the ECHAM model), then the entire arable land area would be potentially suitable for ECB between 2025-2030 (Fig. 7e). The probability of an occurrence of the partial second generation inside two main maize production areas (i.e., the southeast and northwest of the country) increases significantly after 2025. The permanent presence of a partial second generation might cause higher economical losses since some of the larvae could damage stems and husks during grain filling. ECB is known to feed on a number of other plant species that eventually might have a higher nutritional value or water content than maize. In such case higher rates of development should be expected and, in warm years, such change of diet could enable development of the fifth ECB instar before the first frosts and the bivoltine life cycle could be established. If we assume no change of the host preferences by the ECB, the simulations based on the SRES-B1 emission scenario, low climate sensitivity, and the NCARPCM model show extremely low probability of a bivoltine population establishment, even prior to 2075. A combination of an SRES-A2 emission scenario and high climate sensitivity with HadCM, ECHAM and NCARPCM GCM´s would on the contrary enable the existence of a stable bivoltine population in the southeast between 2025 and 2050. According to these scenarios, by 2050, two generations of the pest will be common in the northwest of the country, with the southeast population area reaching $CS_{II} > 0.90$ (Fig. 7e,f).

In order to assess possible changes in synchronization between the pest and host (i.e. grain maize) development, we estimated the expected duration of phenological stages using crop growth model CERES-Maize (Jones and Kiniry, 1986). This model was extensively calibrated by Žalud and Dubrovský (2002) and results indicate relatively small shifts in mutual timing of ECB and maize stages (Fig. 10b). Even though the crop model predicts shortening of some maize developmental stages (especially from flowering to maturity) under climate change, we have to take into account the possibility of earlier sowing dates, which will mitigate the effect of higher overall temperatures on the shortening of maize development. The results show that a large part of the second ECB generation will manage to complete its life cycle before the harvest (Fig. 10a) in most years.

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Model regions and climate change impact analysis - Austria

The major field agricultural production area of Austria is located in the north-eastern part of the country with the regions 'nördliches Weinviertel', 'Marchfeld', 'Bruck an der Leitha' and 'Neusiedl am See' (Fig. 1) (Huber 1995). The region is situated between 47°40'N and 48°60'N as well as 15°13'E and 17°00'E and is mostly a flat area with minor variations in elevation, ranging from 150 to 536 m. The region is influenced by a semi-arid climate with low annual rainfall. The annual average temperature varies from 8 to 10°C and annual precipitation sum ranges from 410 to 550 mm (Müller 1993).

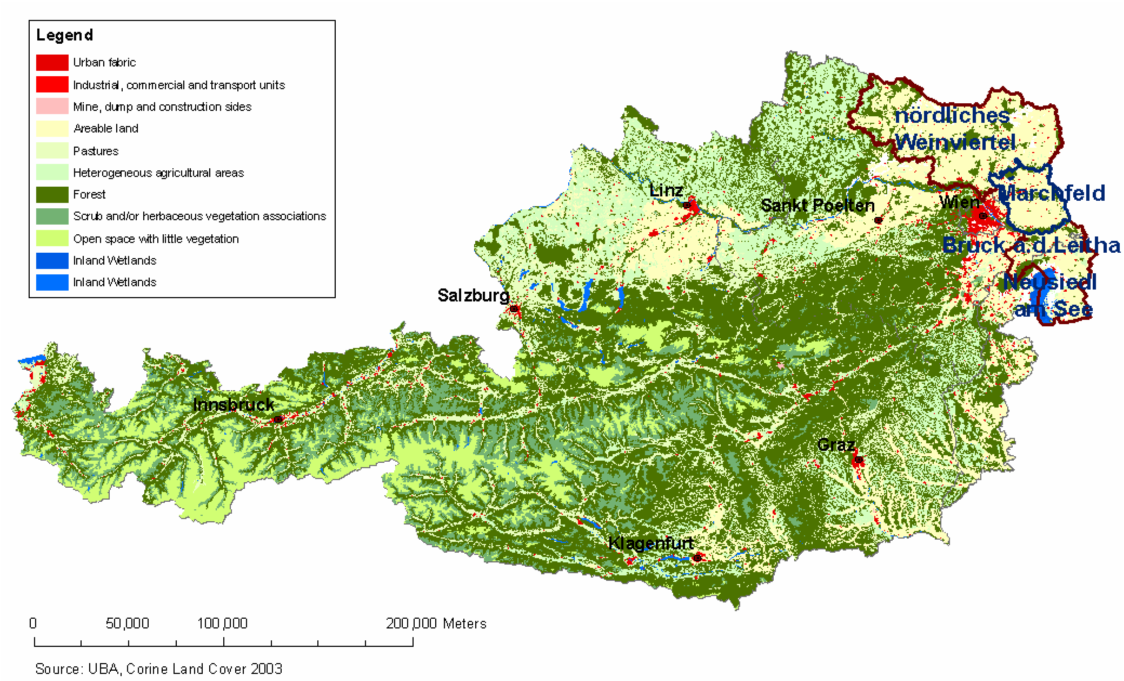


Fig. 1: Corine Land Cover Austria

The Marchfeld region

The first simulations were performed in the Marchfeld region (Fig. 2), using a moderately good database. The Marchfeld area is the largest plain of Austria and geologically belongs to the Vienna Basin, a wide landscape filled with tertiary sediments. It reaches until the River Danube in the south, the River March in the east, the hilly regions of the Weinviertel in the north and the Bisamberg Hill in the west (Fig. 1 and 2). In the northern parts stretches of diluvia gravel are partly covered with loess. Between the towns Deutsch-Wagram and Marchegg, a terrace of approximately 10 m in height divides the plain into the Upper and the Lower Marchfeld Plain (Österreich Lexikon, 2003). The most important soil types in the Marchfeld region are fluvisols near by the Danube and March, calcic and hablic chernozems. Fuchsenbigl, located in the north-eastern part of Austria (latitude 48.322, longitude 17.000, elevation 149 m, see Fig. 2), was chosen as experimental field.

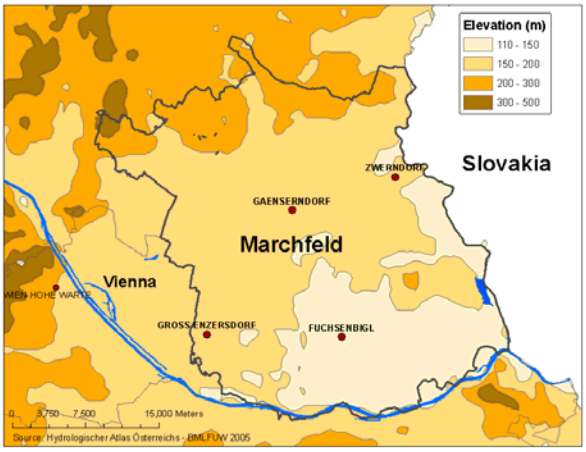


Fig. 2: The Marchfeld region

Weather data

The minimum input weather data in DSSAT are the daily values of maximum and minimum temperature [°C], precipitation [mm] as well as solar radiation [MJ m^{-2}]. The data used for calibration were provided by the Austrian weather service (ZAMG), with a time series ranging from 1989 to 1999. For Fuchsenbigl maximum and minimum daily air temperature as well as rainfall were available. Solar radiation were used from the station Gross-Enzersdorf.

Soil data

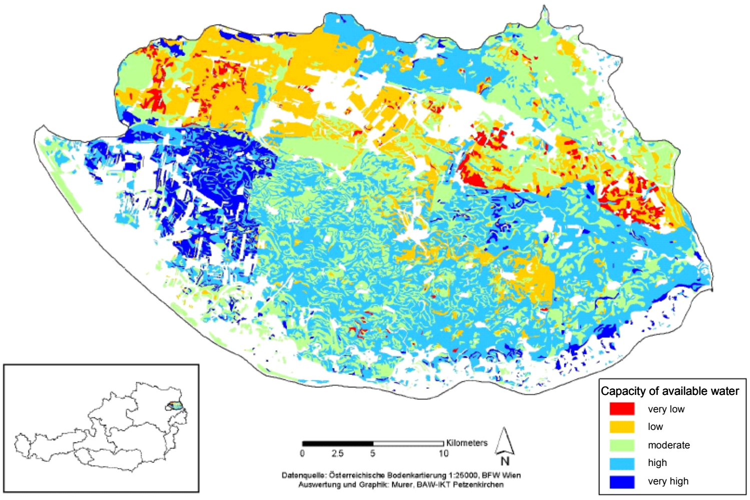
Soil input data were derived from soil pits at the experimental sites. According to the FAO Soil Classification (FAO-UNESCO 1988) the soil type in the area of Fuchsenbigl is classified as calcic chernozem. Explicitly, it is described as chernozem on fine calcareous sediments over gravel and sand. The soil type of the mineral soil surface layer at this site is a loamy sand and sandy silt loam with a very deep groundwater table (below 6 m depth), which is typical of the Marchfeld region (Eitzinger et al. 2003). The intensely cultivated soil has a thickness of around 1.5 m (Tab. 1). The 50 cm thick A horizon (mineral horizon with accumulation of organic substances) leads to a high fertility.

Soil depth (cm)	Wilting pont (vol. %)	Field capacity (vol. %)	Soil saturation (vol. %)	Clay (%)	Silt (%)	Sand (%)
15	23	38	53	25	55	20
30	21	32,6	53	25	55	20
45	22,3	33,8	45	24	50	26
90	20,3	30,8	45	24	50	26
150	15,9	23,1	41	5	15	80

Tab. 1: The main physical properties of the soil profile used by DSSAT CERES-Wheat model for the calibration (ploughed until 25 cm)

The digital Austrian Soil Map 1:25 000 indicates for the Marchfeld region more than 255 different soil types. For each soil type data about soil profiles (down to 1 m depth), texture, pH , humus content etc. are available in the Soil Map. Using this data Murer et al. (2004) calculated permanent wilting point, field capacity, saturation point and plant available field capacity according to a method in Bodenkundliche Kartieranleitung (AG BODEN 1994). To generalize the investigation area, Murer et al. (2004) distinguished five soil classes by the amount of total available water capacity, a crucial factor for plant growth (Tab. 2). A general map of the 5 classes of the available water capacity from the Marchfeld arable soils is shown (Fig. 3).

The soil classification was resumed, additionally average values for the physical and chemical soil properties (field capacity, wilting point, saturation point, texture, pH, calcium content) weighed by the area of the soil types were calculated.



Classification	Available water capacity (mm)
very low	< 60
low	60-140
moderate	140-220
high	220-300
very high	> 300

Fig. 3: Capacity of available water of the mineral soils from the agricultural areas Marchfeld (Murer et al. 2004).

Tab. 2: Classification of the capacity of available water of the mineral soils according AG Boden (1994)

Management data

Management data for the experimental field was available from the Bundesanstalt für Pflanzenbau (1989-1999). Winter wheat (*Triticum aestivum* L.) – cultivar "Capo" was tested as a cultivar and is currently grown on large acreages in Marchfeld. The planting date was chosen for the middle of October, the sowing density was 350 kernels/m², the row spacing 12 cm and the planting depth 3cm. The soil was evenly ploughed before sowing (25 cm depth). The crop was managed with regional standard fertilization (two applications in April, in sum 120 kg ha^{-1} of nitrogen and 30 kg ha^{-1} of phosphor).

The effect of climate change on the cereal crop production

CERES calibration

The DSSAT CERES model for winter wheat cultivar "Capo" was calibrated by using agrotechnological, phenological, yield and weather data from the experimental site Fuchsenbigl, during the period 1989-1994, 1996, 1998 and 1999. The difference between simulated and observed dates of anthesis and physiological flowering varied between 0 and 4 days. Simple linear regressions were computed to determine the coefficient of determination (R^2) between measured and simulated flowering date and yield data. The flowering date was simulated with a R^2 of 0.9 (Fig. 5a). Simulated grain yield agreed in most cases with the measured data and the R^2 is with 0.73 reasonably fine (Fig. 4b and 5). The mean validation difference over 9 years between measured and simulated yield was 101 kg ha^{-1}.;

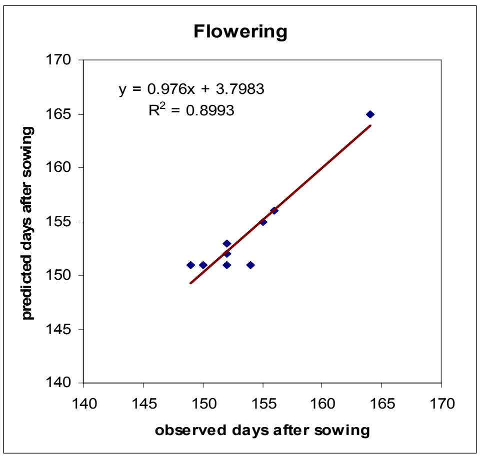


Fig. 4a: Relationship between observed and predicted flowering date,

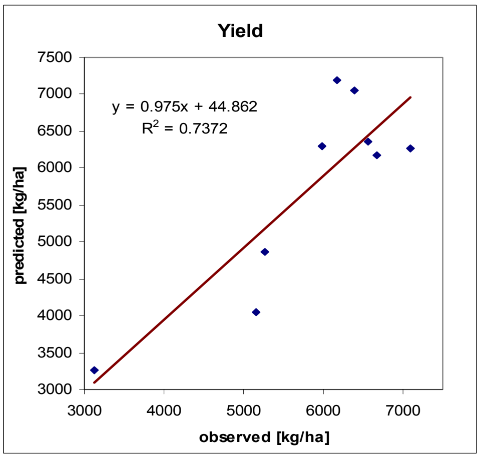


Fig. 4b: Relationship between observed and predicted yield

The annual average yield in Fuchsenbigl is around 5700 kg ha^{-1} in the calibration years. A noticeable low yield was obtained in the year 1993 with 43% below the average production. This can be explained by the markedly low precipitation in the months April, May and June. The low precipitation and high potential evapotranspiration in 1993 also led to a low simulated yield. The results indicate that the model delivers reasonable values for years with extreme conditions (Fig. 5).

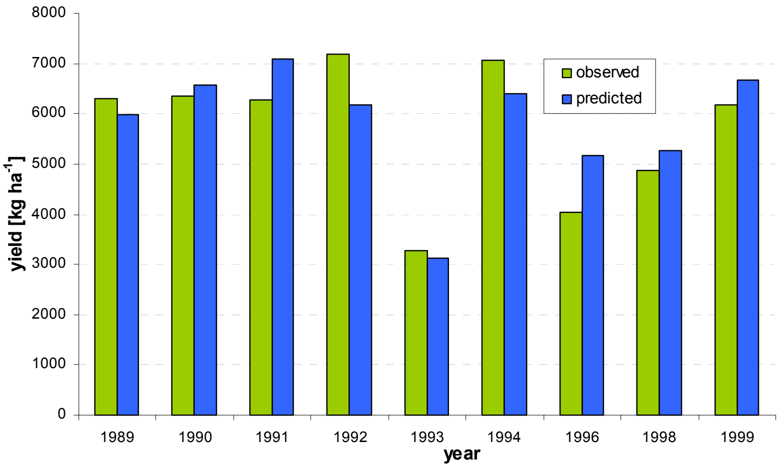


Fig. 5: Comparison between observed and predicted winter wheat yields [kg ha^{-1}] in Fuchsenbigl, Marchfeld

In a next step the growth cycle of winter wheat was simulated using 5 different soil classes in the Marchfeld. Figure 6 shows the yields for each year and soil class. The base soil corresponds to the input data of the experimental field.

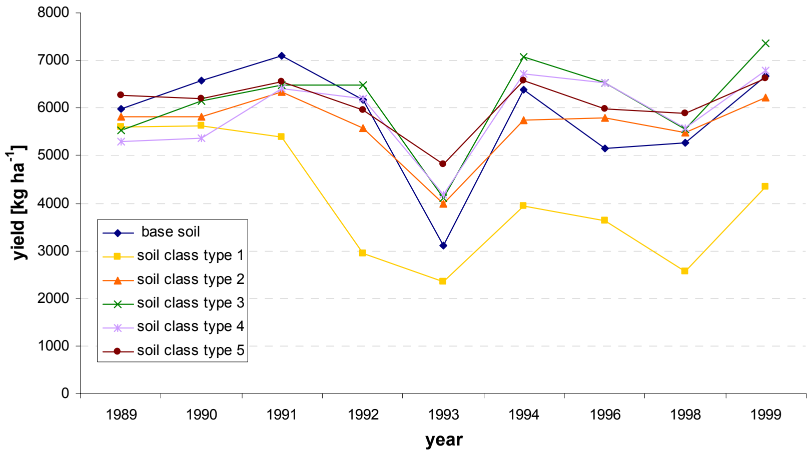


Fig. 6: Yield simulations for different soil types in Marchfeld (1989-1994, 1996, 1998 and 1999)

The soil with the lowest capacity of available water (soil class type 1) resulted in approximately 31% and soil class type 2 around 3% lower yield than the base soil for the 9 investigated years. Soil classes 4-6 result in average in a higher yield than the base soil (from 1 to 5 %).

These findings suggest, that on soils with an available water capacity over 140 mm weather will be limiting factor for crop development in average years.

Modifications by scenarios

Since new climate change scenarios for this project are still not available; already available regional scenarios for north-east Austria were used to perform the first simulations. These are based on IPCC IS92a scenarios, which were realized with the ECHAM4/OPYC3 global circulation model (GCM).

GCMs are suitable to reproduce the large scale behaviour of climatic parameters, but are not able to acceptably simulate local scale effects. To provide climate scenario data at the local scale it is necessary to use some kind of downscaling. The 'analogue technique' was used as downscaling tool on monthly and daily scales (Zorita and v. Storch 1999, Matulla et al. 2004). 500 potential years were calculated for the period 2020 (mean between 2010 and 2030) as well as for the period 2040 (mean 2030 and 2050). According to these scenarios annual temperatures are expected to rise around 1.9°C in the 2020s and 2.5°C in the 2040s in the selected region.

Winter wheat growth and development were simulated for climate change scenarios as follows:

(a) Climate effect representing a change in weather input (only air temperature according to scenarios) compared with the present climate but no change in CO_2 concentration in the atmosphere (330 ppm) (scenario 1 and 2)

(b) Climate effect representing a change in weather input (air temperature and precipitation according to scenarios) compared with the present climate but no change in CO_2 concentration in the atmosphere (330 ppm) (scenarios 3-6)

(c) Climate effect representing a change in weather input (air temperature and precipitation according to scenarios) compared with the present climate and CO_2 effect in the atmosphere (year 2020 = 429 ppm and year 2040 = 495 ppm) (scenarios 7-12)

The DSSAT CERES model was used in order to determine the vulnerability of current agricultural management scenarios on the selected crops. The first simulations were run with the climate change effect, which included the impact of changes in air temperature (2020 = scenario 1, 2040 = scenario 2).

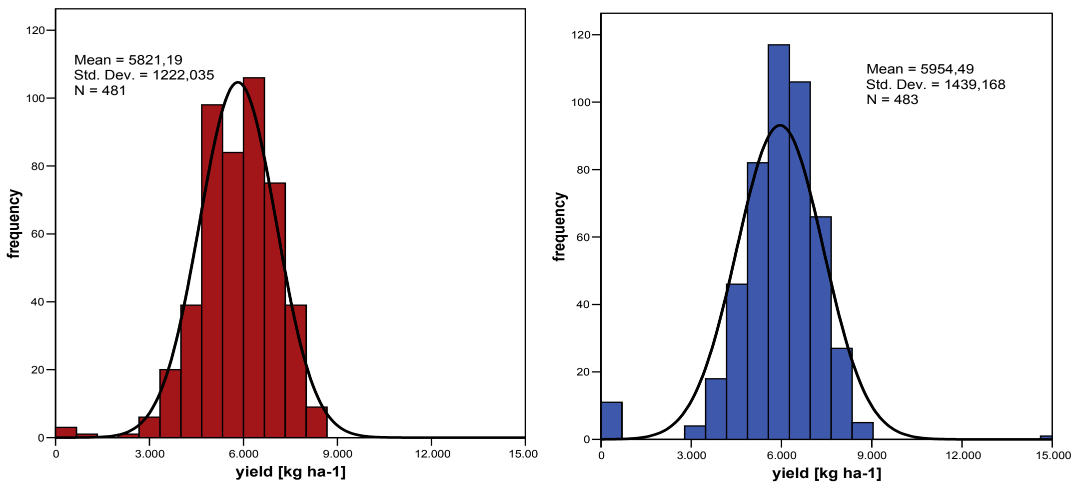


Fig. 7a: Histogram and curve for standard distribution for yield [kg ha^{-1}] in 2020 according the climate change scenarios

Fig. 7b: Histogram and curve for standard distribution for yield [kg ha^{-1}] in 2040 according the climate change scenarios

A temperature rise of 1.9°C until 2020 would result in an increase of 2 % of the average yield (average yield = 5821 kg ha^{-1}, Std. dev. = 1222) (fig. 7a). Until the year 2040 (+2.5°C) a yield rise of 4 % (average yield = 5954 kg ha^{-1}, Std. dev. = 1439) can be expected (fig. 7b). Std. dev. of 2040 compared to 2020 shows higher yield variability and therefore advanced yield risk for the farmer.

In a second step the simulations were performed taking into account the climate change effects, which include the impact of changes in air temperature and precipitation. On the one hand an increase of 20 % precipitation was assumed and on the other hand a decrease of 20 % precipitation was simulated (fig. 9) (-20% precipitation at 2020 = scenario 3; -20% precipitation at 2040 = scenario 4; +20% precipitation at 2020 = scenario 5; +20% precipitation at 2040 = scenario 6).

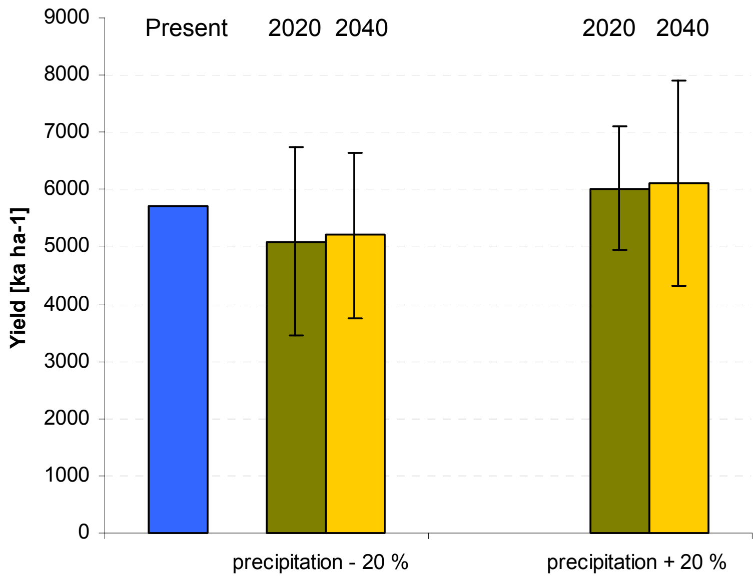


Fig. 8: Annual average yield [kg ha^{-1}] at 2020 and 2040 with changes in air temperature and precipitation (+/- 20%) in the 21st century compared with the present average yield (error bars indicate ±standard deviation)

Figure 8 shows the annual average yield at present as well as 2020 and 2040 with the climate change scenario. If in the first part of the 21st century precipitation decreases around 20%, a yield loss of around 9% in 2020 and 11% in 2040 can be expected. A temperature rise until 2040 can increase the yield (Fig. 7), but a reduced precipitation would counterbalance this positive effect.

More precipitation and higher temperature have a positive effect on the crop development. A mean increase of 5% until 2020 and 7% until 2040 can be expected.

The DSSAT crop model has also shown to be sensitive to carbon dioxide (CO_2) concentrations (Tsuji et al. 1998). Thus, in a third step the changes in photosynthesis and evapotranspiration caused by higher levels of atmospheric CO_2 were simulated. The direct effect of an increased CO_2 concentration incorporated the influence of changes in climate and the enhancement of plant growth as a result of elevated atmospheric CO_2 concentrations. In this case, the atmospheric CO_2 concentrations were supposed to be 330 ppm for the baseline climate (validation years), 429 ppm (+30%) for the 2020s and 495 ppm (+50%) for the 2040s.

The direct CO_2 effect increased grain yield for wheat in the 2020s up to 9 % over the baseline (scenario 7) (Fig. 9). If precipitation increases 20% and the CO_2 concentration is 429 ppm the yield will be 11% over the baseline (scenario 8). With precipitation decreasing (-20%) but a CO_2 concentration of 429 ppm the yield will reduce around 4% (scenario 9) (fig. 10).

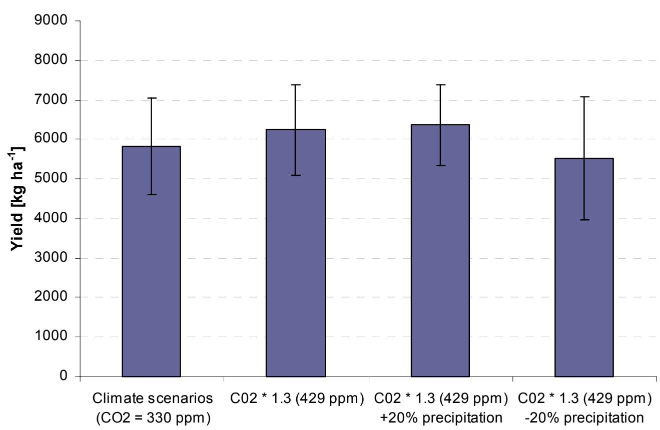


Fig. 9: CO_2 effects and climate change scenario 2020 (error bars indicate ±standard deviation)

In fig. 10 the direct CO_2 concentration effect in the year 2040 is shown. An increased grain yield will be up to 15% (scenario 10), with 20% more precipitation up to 14% (scenario 11) and with 20% less precipitation up to 3% (scenario 12) over the baseline.

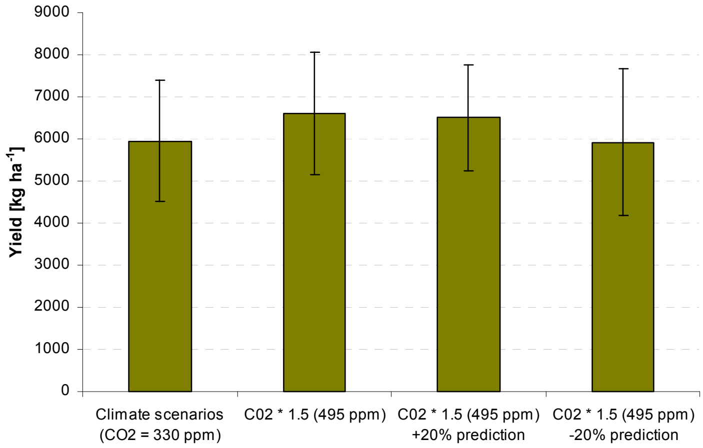


Fig. 10: CO_2 effects and climate change scenario 2040 (error bars indicate ±standard deviation)

A statistical summary of all climate change simulations for 2020 and 2040 are shown in Table 3.

a)

	Climate scenarios	precipitation - 20 %	precipitation + 20 %	$C0_2$ * 1.3 (429 ppm)	$C0_2$ * 1.3 (429 ppm) +20% precipitation	$C0_2$ * 1.3 (429 ppm) - 20% precipitation
Mean	5821	5091	6022	6248	6368	5519
Stan.dev.	1222	1650	1069	1147	1022	1564
Min	200	65	235	251	265	53
Max	8563	8774	8827	8830	9046	8971
Range	8363	8709	8592	8579	8781	8918
Median	5898	5189	6096	6356	6415	5611
N	481	481	481	481	481	481

b)

	Climate scenarios	precipitation - 20 %	precipitation + 20 %	$C0_2$ * 1.5 (495 ppm)	$C0_2$ * 1.5 (495 ppm) +20% precipitation	$C0_2$ * 1.5 (495 ppm) - 20% precipitation
Mean	5954	5204	6105	6596	6501	5921
Stan.dev.	1439	1792	1290	1451	1262	1734
Min	2	2	2	2	2	2
Max	15045	9055	9262	18901	9816	10821
Range	15043	9053	9260	18899	9814	10819
Median	6046	5299.5	6214	6701	6571.5	6087
N	483	484	484	483	484	484

Tab. 3: (a) statistical summary of climate change scenarios and CO_2 effects for 2020 (b) statistical summary of climate change scenarios and CO_2 effects for 2040

Conclusion and next steps

The climate change scenarios for near future show the greatest effect when CO_2 increases. Up to 15% more yield can be expected when CO_2 increases by 50% until 2040. The results for the fertilising effect of ambient CO_2 levels and the positive yield changes agree with other published studies (Cure and Acock 1986, Parry 2000, Alexandrov et al. 2002, Eitzinger et al. 2003). Simultaneously the variance increases and consequently the yield variability. This provides a higher yield risk for the farmer. In a next step winter wheat should be simulated for the 5 soil classes in Marchfeld and a GIS map with the climate change effects should be created (crop yield changes). As second crop spring barley should be calibrated and validated. Analysis of the drought damage potential and crop water use efficiency as influenced by climate change effects and regional conditions should be explored.

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Model regions and climate change impact analysis - Bulgaria

Bulgaria (Fig. 1), located on the Balkan Peninsula, includes 31% Lowlands (0-200 m), 41% hills (200-600 m), 25% highlands (600-1600 m) and 3% mountains (> 1600 m). The Balkan Mountains split the country into north and south Bulgaria, and they have a strong effect on the air temperature regime. The annual mean air temperatures in Bulgaria vary from -3.0° to 14.0°C, depending on the location and elevation. Air temperature normally reaches a minimum in January, and a maximum in July. The monthly mean temperature varies from -10.9 to 3.2°C in January and from 5.0 to 25.0°C in July. Total precipitation depends on the circulation patterns, site elevation, and the specificity of local orographic features. Annual mean total precipitation is approximately 500-650 mm, with an annual variation ranging from 440 to 1020 mm. The highest monthly values are measured in June, and at some places in May, with the mean total varying between 55 and 85 mm. February, and sometimes March and September, are the driest months, with mean totals varying between 30 and 45 mm. Mean precipitation during the warm months, e.g., April through September, is 333 mm, with a standard deviation of 72 mm. Mean precipitation varies from a maximum of 573 mm in the Balkan Mountains to a minimum of 211 mm in southeast Bulgaria.

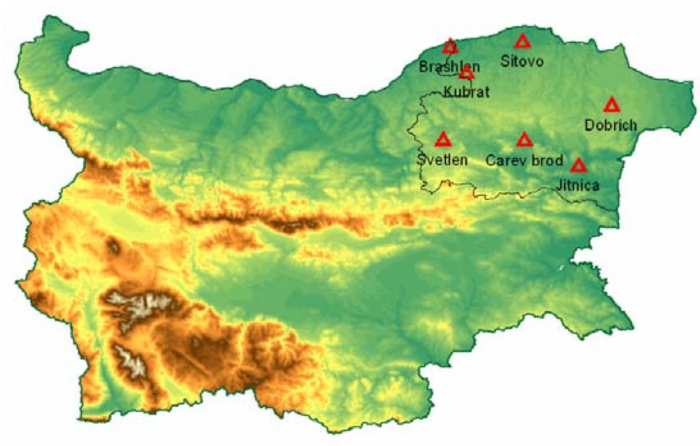


Fig. 1. Bulgaria, selected NUTS2 (north-east) region and experimental crop variety stations (△) in it

North- East NUTS2 region

The North-East region covers 19 973 km2 or 18% of the country's total area. The relief is varied, tending towards plains and hillsides. Vast valleys stretch down to the steep and severely eroding banks of the Danube River. While the relief of the Dobrudja plain is largely flat, canyon-shaped valleys are also a scenic part of the landscape. The south is dominated by the eastern ridges of the Balkan mountains. Eastwards, the Black Sea coast has beautiful scenery, its deeply indented relief being the perfect prerequisite for both the building of many ports and the development of tourism.

While the North-East region's climate is mainly influenced by the moderate continental belt, the climate in the region's eastern parts is mainly determined by the impact of the Black Sea. The low annual precipitation here, below 500 mm, has led to artificial irrigation of agricultural areas. The average annual temperature is around 11- 12oC, being higher along the Black Sea coast and in the areas close to the Danube River.

The region's geographic location is its second major asset, reflecting its good transport links and the opportunities it offers for future economic growth. With access to both the Danube River and the Black Sea, this should strengthen the region's role as a geopolitical centre connecting the country with central Asia and with countries in the Black Sea region. Furthermore, parts of the 7th European traffic corridor cross the region along the Danube River, which is an important link to North-eastern Europe.

A strongly developed agricultural sector is the region's major advantage, crop production in particular flourishing due to the favourable climate and the region's vast plains. Gross value added (GVA) from the region's agricultural sector to the national economy is second highest after the South-Central region (in 2002, it was equal to 21.8% of national GVA of the agricultural sector). Overall, the output from crop production has turned the region into the country's breadbasket. Black soil in the Ludogorie and Dobrudja plain is the most fertile soil in the region, and large quantities of crops are grown here. The region has the largest share of arable land amongst the six regions, accounting for 51.1% of its total area in 2002.

The region has limited water resources. Most of the region's water is supplied by the Kamchia, Batova and Danube Rivers. The Fishek, Ticha and Konevo artificial lakes, which are built on the Kamchia River, are very important for the regional economy. The rivers in Ludogorie and Dobrudja, used for household water supply, frequently dry up in the summer, but this shortage is compensated for by underground water deposits.

Climatic, soil, crop and agrotechnologial data

Daily weather data of maximum and minimum air temperature, precipitation and simulated (e.g. Georgiev and Slavov, 1993) solar radiation for the period 1961-2000 were gathered from the weather stations, nearest to the selected experimental crop variety stations (Fig. 1).

Soil profiles, delivered during previous crop-weather model evaluation studies (e.g., Alexandrov and Eitzinger, 2001), applicable for the Bulgarian locations, were applied as required model inputs (Table 1). Additional soil profiles such as “medium silty clay”, “medium silty loam”, and “medium sandy loam” were also created on the base of field experiments and scientific literature.

Station	Soil type
Svetlen	Podzolized chernozem
Brashljan	Moderately leached chernozem
Kubrat	Podzolized chernozem
Sitovo	Leached chernozem, heavy loamy
Carev brod	Calcareous chernozem
Dobrich	Typical chernozem, heavy loamy
Jitnica	Calcareous chernozem

Table 1. Soil types of the selected experimental crop variety stations

Phenological, agrotechnological and crop yield (winter wheat and maize) data were obtained from the Bulgarian National Variety Commission of the Ministry of Agriculture.

The effect of climate change on the cereal crop production

Maize (CERES model) - calibration and validation

As a first step, the CERES model parameters determining maize development and phenological stage occurrence in the selected region were calibrated. Figure 2 represents a comparison between the simulated and observed silking and maturity dates of maize for the investigated 21 experimental crop variety stations across the country. The difference between the simulated and observed silking dates during the period of calibration (1984-1990) in most cases (108 cases from total 112 field experiments) is up to 1 week. The deviation of the simulated maturity dates, relative to the observed ones is less than 2 weeks, except 2 cases. A better view for the distribution of the simulation error regarding these two phenological stages can be obtained in Figure 3.

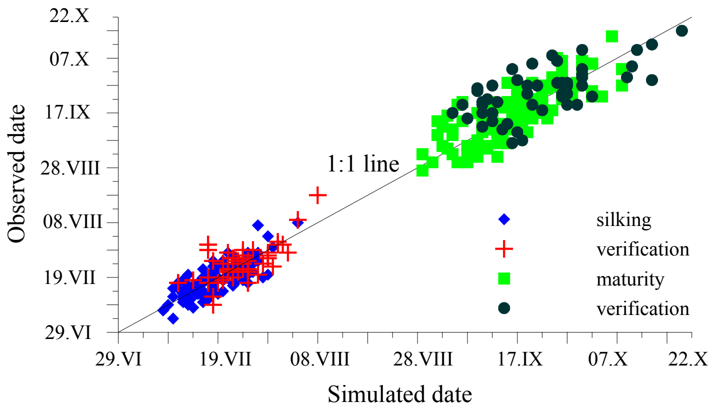


Fig. 2. Comparison between simulated and observed silking and maturity dates of maize during the periods of calibration (1984-1990) and verification (1991-1993)

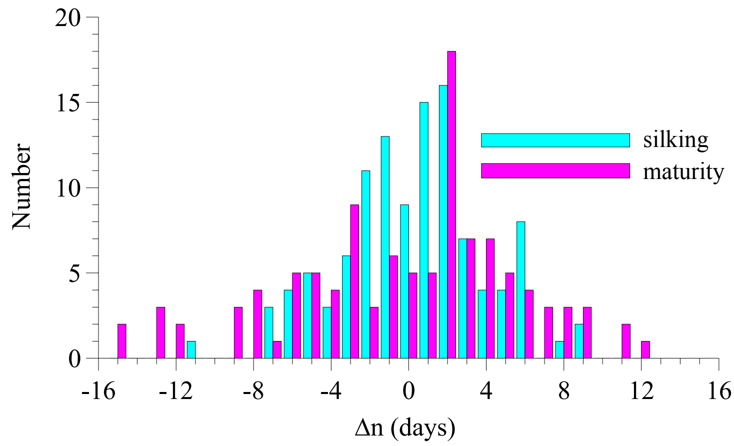


Fig. 3. Number of deviations (Δn) between simulated and observed silking and maturity dates of maize during the period of calibration (1984-1990)

After identification of the CERES model parameters, characterizing the vegetative and reproductive periods of maize crop, the model parameters related to maize yield formation were optimized. The biological meanings of these parameters are related to the maximum grain number for one crop and the rate of grain filling. Within 78.8% of the total maize field experiments the error of the simulated number of grains/m^2, relative to the measured one is less than 20%, whereas the deviation of the simulated maize grain weight from the measured weight is higher than 20% only in 6 cases (Fig. 4).

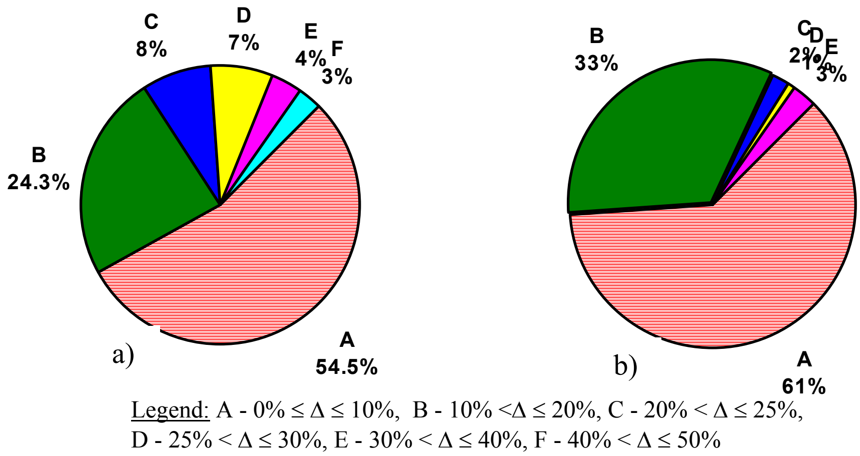


Fig. 4. Deviation (Δ) between simulated and measured number of grains/m^2 (a) and grain weight (b) of maize (1984-1990)

The deviation between the simulated maize grain yield and the measured one is less than 10% for more than 1/3 (44%) of all field experiments and it is less than 20% for 73% of all cases (Fig. 5 ands 6).

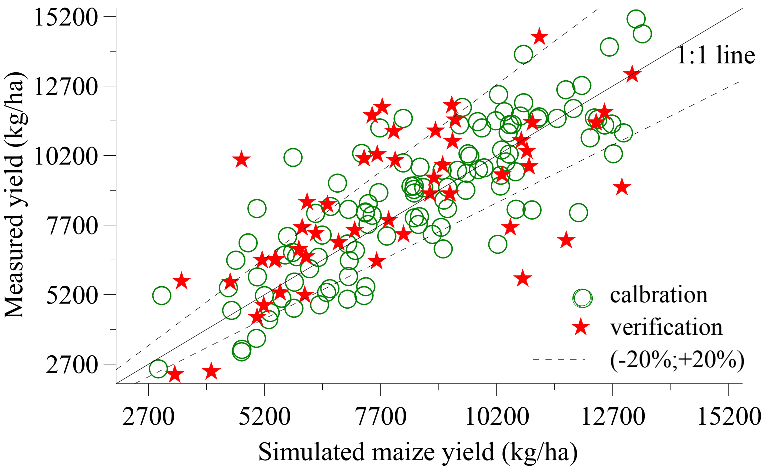
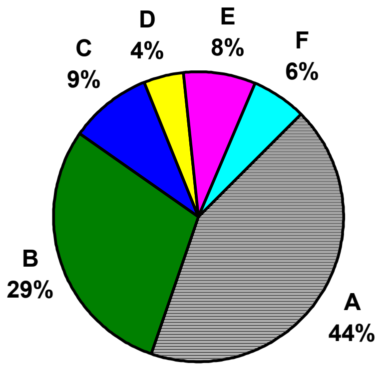


Fig. 5. Comparison between simulated and measured maize grain yield during the periods of calibration (1984-1990) and verification (1991-1993)



Legend: A - 0% ≤ Δ ≤ 10%, B - 10% <Δ ≤ 20%, C - 20% < Δ ≤ 25%, D - 25% < Δ ≤ 30%, E - 30% < Δ ≤ 40%, F - 40% < Δ ≤ 50%

Fig. 6. Deviation (Δ) between simulated and measured maize grain yield (1984-1990)

It is necessary to specify again that up to 20% deviation of the simulated crop yield, relative to the observed one is considered as a good result in this study, following for example Chirkov, (1969), Procerov and Ulanova (1961), Slavov and Vitanov (1977).

In order to validate the calibrated CERES model parameters for maize, the model was verified on independent agrometeorological data set from the selected region including the periods 1980-1983 and especially 1991-1993. The differences between the simulated and observed silking and maturity dates of maize are above 7 and 14 days, respectively only in 6 cases from 1991 to 1993. The deviation between the simulated and observed maturity dates varies up to 1 week in 1/3 of the experiments, used for model verification. The simulation error, related to the number of grains/m^2 and grain weight is less than 20% within 60 and 84% of the cases, respectively. As a result, the deviation between the simulated and measured maize grain yield is on the interval 0-25%, carried out during the period 1991-1993. The agrometeorological data from 1980 to 1983, available for some of the experimental crop variety stations, were also used for model verification.

Winter wheat (CERES model) - calibration and validation

The CERES model for winter wheat was also adapted for the environmental conditions in the selected region by applying crop, weather and agrotechnological data from 1980 to 1993. The years from 1984 to 1990 were used for calibration of the model parameters and the rest years were left for model verification. The obtained results are presented in Figures 7-11.

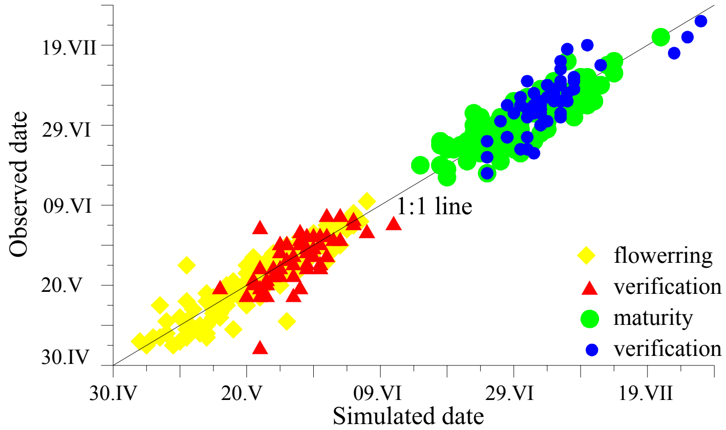


Fig. 7. Comparison between simulated and observed flowering and maturity dates of winter wheat during the periods of calibration (1984-1990) and verification (1991-1993)

The departure of the simulated dates of winter wheat flowering and maturity, relative to the observed ones is less than 3 days in 80 and 68%, respectively for all field experiments executed from 1983 to 1990. This difference is higher than 1 week only for 4 and 6 cases, respectively in the years of model verification from 1991 to 1993 (Fig. 7 and 8). The model simulation error for the number of wheat grains/m^2 and grain weight is less than 20% for 74 and 93%, respectively of the field experiments, carried out from 1983 to 1990 (Fig. 9).

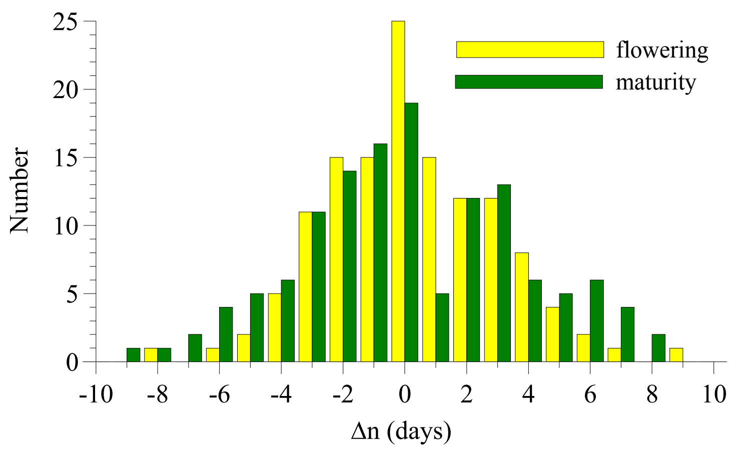
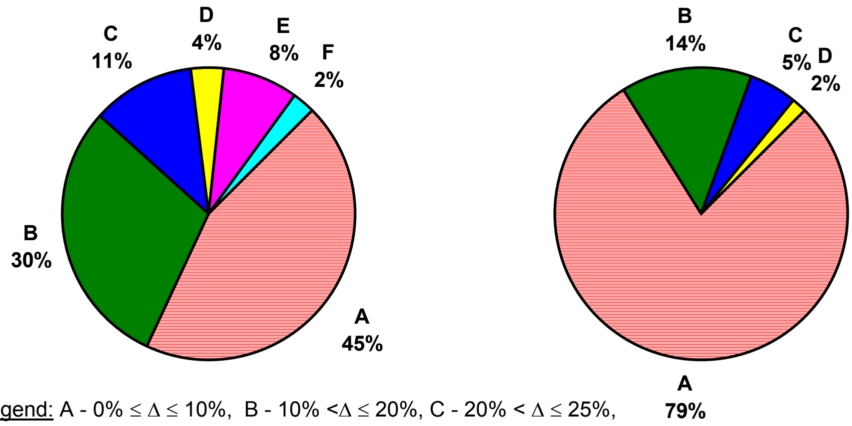


Fig. 8. Number of deviations (Δn) between simulated and observed flowering and maturity dates of winter wheat during the period of calibration (1984-1990).



Legend: A - 0% ≤ Δ ≤ 10%, B - 10% <Δ ≤ 20%, C - 20% < Δ ≤ 25%, D - 25% < Δ ≤ 30%, E - 30% < Δ ≤ 40%, F - 40% < Δ ≤ 50%

Fig. 9. Deviation (Δ) between simulated and measured number of grains/m^2 (a) and grain weight (b) of winter wheat (1984-1990)

As a result of the above good model results, the deviation between the simulated and measured grain yield of winter wheat is also considered as a satisfactory performance of the CERES model (Fig. 10-11). The simulation error for the main periods of calibration (1984-1990) and verification (1991-1993) is beyond the ±20% interval only for 28% of the considered all field experiments. In a similar way, as it was done for maize crop, agrometeorological data from 1980 to 1983, when available, were also applied for additional model verification.

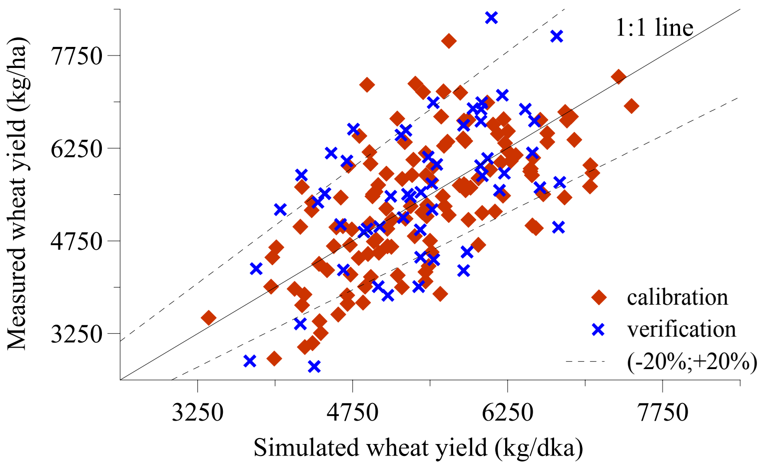
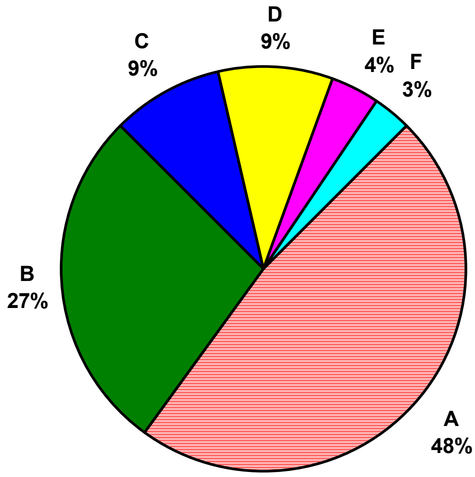


Fig. 10. Comparison between simulated and measured grain yield of winter yield during the periods of calibration (1984-1990) and verification (1991-1993)



Legend: A - 0% ≤ Δ ≤ 10%, B - 10% <Δ ≤ 20%, C - 20% < Δ ≤ 25%,
D - 25% < Δ ≤ 30%, E - 30% < Δ ≤ 40%, F - 40% < Δ ≤ 50%

Fig. 11. Deviation (Δ) between simulated and measured grain yield of winter wheat (1984-1990)

There was found good agreement between real phenological stages and yield of important crops in the selected region and phenology and yield, estimated with the CERES model. Overall, the model test results were very good. The results obtained indicated a satisfactory performance of the applied simulation models for winter wheat and maize in the selected environments.

Changes in crop growing season

All transient GCM climate change scenarios used in the DSSAT CERES simulation model projected a shorter vegetative and reproductive growing season for maize and winter wheat in the selected region during the 21st century. These changes were caused by the predicted temperature increase of the GCM scenarios. The duration of the regular crop-growing season for maize was between 5 (HadCM2) and 20 (GFDL-R15) days shorter. Maturity dates for maize were expected to occur between 17 days and 29 days earlier in the 2050s (Fig.12). The predicted changes in the crop-growing duration for maize in the 2050s were less for the HadCM2, CGCM1, and CSIRO-Mk2b climate change scenarios than the changes predicted by the ECHAM4 and GFDL-R15 models. These last two models simulated a higher increase of air temperature in Bulgaria, especially the GFDL-R15 model, during the summer months July and August. The GCM climate change scenarios for the 2080s projected a decrease in maize growing season by 17 (CSIRO-MK2b) to 39 (ECHAM4 and CGCM1) days. This will cause a shift in harvest maturity dates for maize from September to August at the end of the 21st century.

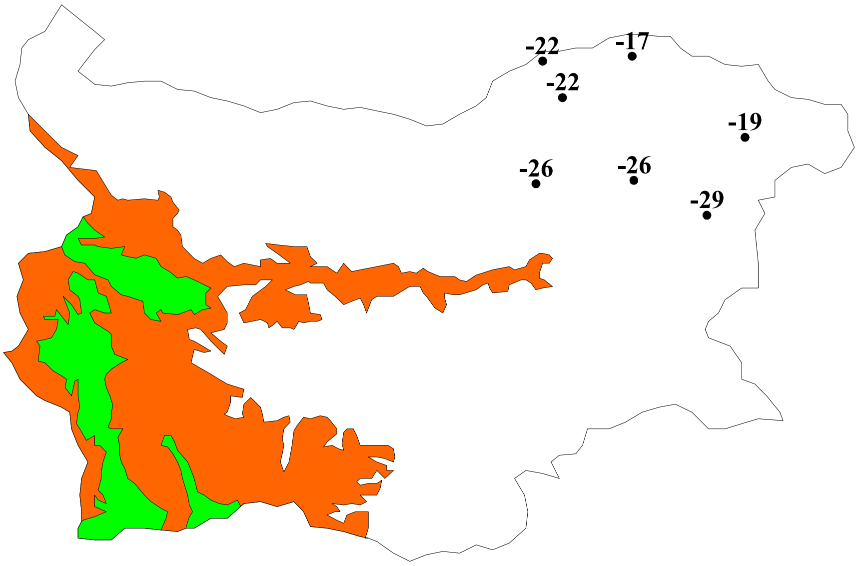


Fig. 12. Changes (in days) of the duration of maize growing season in the selected region under the ECHAM4 climate change scenarios for the 2050s; CERES model

Winter wheat showed a decrease in growing season duration for the 2020s, varying between 3 days (HadCM2) and 14 days (GFDL-R15). The projected decreases in growing season for the 2020s, 2050s, and 2080s were less for the HadCM2 model, which predicted a smaller air temperature increase during November and December. Even a slight decrease in monthly air temperature in November was projected for the 2020s under the HadCM2 climate change scenario. The transient GCM climate change scenarios predicted that harvest maturity for winter wheat would be approximately one to two weeks earlier in the 2050s, and between two to three weeks earlier in the 2080s.

Changes in crop yields

The decrease in simulated maize yield for the next century was primarily caused by shorter growing season duration and reductions in precipitation. All GCMs simulated a decrease in precipitation from March to June for the 2080s, which affected soil moisture recharge during the spring and the early developmental stages of maize. The simulated increase in maize grain yield for the HadCM2 climate change scenario for the 2020s was due to a relatively low projected increase in air temperature, as well as a predicted increase in precipitation in July. Because maize is a C_4 crop, an increased level of CO_2 alone had no significant impact on either maize crop growth, and development or final yield (Tables 3-5, Fig. 14). Maize yield decreased by 3 to 8% in the 2020s for the ECHAM4, CGCM1, and CSIRO-Mk2b model scenarios. The projected decrease was highest for the GFDL-R15 model, e.g., between 8 and 14%, while the HadCM2 scenario projected an increase from 4 to 12% for the next decades. A slight increase at the most experimental stations in Northeast is even projected under the HadCM2 climate change scenario for the 2050s. The decrease in simulated maize yield for the 2050s ranged for most stations from 10 to 20% for the ECHAM4, CGCM1, CSIRO-Mk2b, and GFDL-R15 GCM scenarios. The largest decrease in maize yield is expected to occur at the end of the century.

Table 3. Departures of grain yield (%) for maize and winter wheat under transient global climate model scenarios for the 2020s (CO_2=447 ppm), relative to the current climate; CERES model.

Station	**Region**	**ECHAM4**		**HadCM2**		**CGCM1**		**CSIRO-Mk2b**		**GFDL-R15**	
		maize	wheat	maize	wheat	maize	wheat	maize	wheat	maize	wheat
Svetlen	N	-5	15	12	9	-8	18	-8	16	-12	14
Brashljan	N	-8	10	5	12	-6	18	-8	17	-14	8
Kubrat	N	-6	16	10	9	-6	20	-6	15	-11	15
Sitovo	NE	-5	12	5	10	-6	16	-6	13	-12	8
Carev brod	NE	-5	16	12	10	-8	20	-8	17	-12	17
Dobrich	NE	-5	12	5	10	-6	16	-6	13	-12	8
Jitnica	NE	-4	20	11	14	-6	25	-6	21	-12	21
Burgas	SE	-4	14	11	8	-6	12	-7	12	-11	13

Table 4. Departures of grain yield (%) for maize and winter wheat in Bulgaria under transient global climate model scenarios for the 2050s (CO_2=554 ppm), relative to the current climate; CERES model

Station	Region	ECHAM4		HadCM2		CGCM1		CSIRO-Mk2b		GFDL-R15	
		maize	wheat	maize	wheat	maize	wheat	maize	wheat	maize	wheat
Svetlen	N	-12	27	1	30	-11	31	-10	29	-19	29
Brashljan	N	-15	26	-6	29	-11	24	-12	23	-21	17
Kubrat	N	-11	29	-4	32	-10	31	-9	30	-17	31
Sitovo	NE	-10	23	1	29	-10	23	-9	23	-18	18
Carev brod	NE	-12	29	2	32	-11	32	-10	31	-19	32
Dobrich	NE	-10	23	1	29	-10	23	-9	23	-18	18
Jitnica	NE	-11	34	5	38	-10	40	-9	37	-18	37
Burgas	SE	-8	22	6	22	-10	23	-9	22	-18	22

Table 5. Departures of grain yield (%) for maize and winter wheat under transient global climate model scenarios for the 2080s (CO_2=697 ppm), relative to the current climate; CERES model

Station	Region	ECHAM4		HadCM2		CGCM1		CSIRO-Mk2b		GFDL-R15	
		maize	wheat	maize	wheat	maize	wheat	maize	wheat	maize	wheat
Svetlen	N	-19	40	-14	24	-22	40	-12	41	NA	NA
Brashljan	N	-19	17	-21	29	-21	20	-14	30	NA	NA
Kubrat	N	-14	44	-23	25	-18	44	-10	46	NA	NA
Sitovo	NE	-16	23	-10	32	-18	28	-11	36	NA	NA
Carev brod	NE	-18	42	-14	24	-22	42	-12	43	NA	NA
Dobrich	NE	-16	23	-10	32	-18	28	-11	36	NA	NA
Jitnica	NE	-16	47	-12	33	-20	46	-12	49	NA	NA

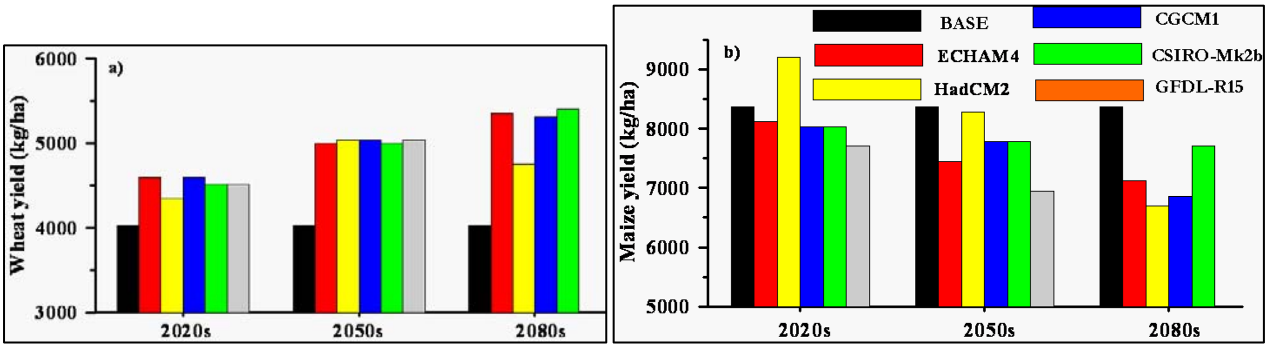


Fig. 13. Yield changes of maize and wheat under GCM scenarios and direct CO2 effect

All transient GCM climate change scenarios for the 21st century, including the adjustment for only air temperature, precipitation and solar radiation, projected a reduction in winter wheat yield. (Tables 3-5). The major cause for this change in impact is that many crops, such as wheat and soybean, belong to the group of C_3 crops, which are more sensitive to changes in CO_2 concentration than the group of C_4 crop, such as maize. The CO_2 effect alone caused an increase in wheat yield 10 to 20% above the baseline (1961-1990) for the 2020s. The simulated deviations of wheat yield increased in the 2050 by more than 20 to 25% for the ECHAM4, HadCM2, CGCM1, and CSIRO-Mk2b climate change scenarios. The increase in wheat yield varied from 14 to 37% for the GFDL-R15 scenario, depending on the location. Despite expected high air temperatures and precipitation reductions during the spring in the 2080s, projected increases in wheat yield varied between 12 and 49% due to the fertilization impact of the increased CO_2 level.

Adaptation options for crops

The sowing dates of spring crops in Bulgaria could shift under the GCM climate change scenarios in order to reduce the yield loss caused by an increase in temperature. The selection of an earlier sowing date for maize will probably be the appropriate response to offset the negative effect of a potential increase in temperature. This change in planting date will allow for the crop to develop during a period of the year with lower temperatures, thereby decreasing developmental rates and increasing the growth duration, especially the grain filling period. The simulated results depicted that the sowing date of maize, for example, in Carev brod (northeast Bulgaria), should occur at least two weeks earlier in the 2080s under the ECHAM4 scenario, relative to the current climate conditions (Fig. 14). It should be noted, however, that although changes in sowing date are a no-cost decision that can be taken at the farm-level, a large shift in sowing dates probably would interfere with the agrotechnological management of other crops, grown during the remainder of the year.

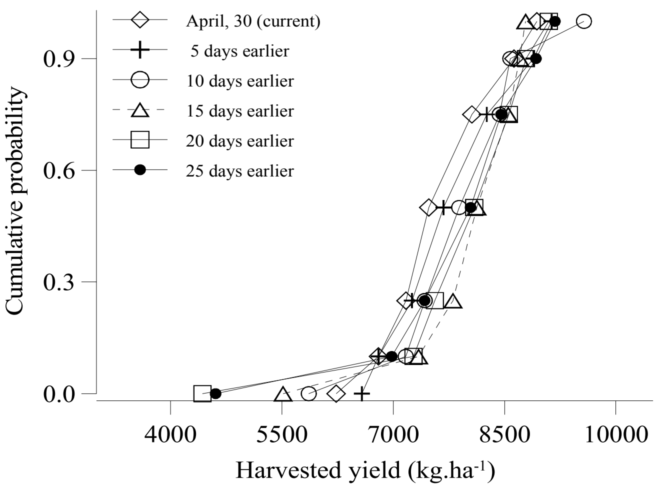


Fig. 14. Cumulative probability function of maize yield at Carev brod (northeast Bulgaria) under the ECHAM4 climate change scenarios for the 2080s and different sowing dates (CO_2=697 ppm); CERES model

Another option for adaptation is to use different hybrids and cultivars. There is an opportunity for cultivation of more productive, later or earlier-maturing, disease- and pest-tolerant hybrids and cultivars. Switching from maize hybrids with a long to a short or very short growing season projected an additional decrease of final yield under a potential warming in Bulgaria. However, using hybrids with a medium growing season, would be beneficial for maize productivity (Fig. 15). Technological innovations, including the development of new crop hybrids and cultivars that may be bred to better match the changing climate, are considered as a promising adaptation strategy. However, the cost of these innovations is still unclear.

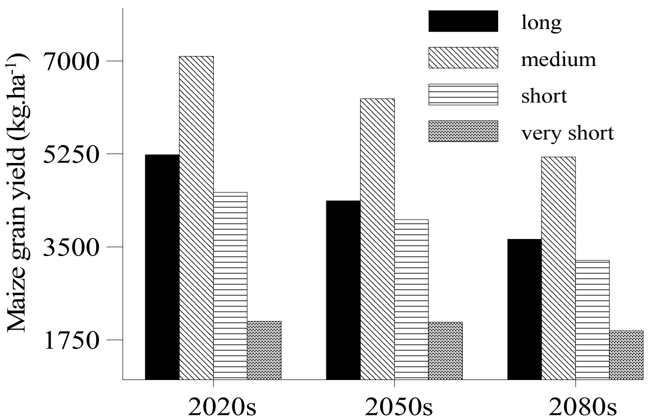


Fig. 15. Simulated maize yield under the HadCM2 transient climate change scenarios for the 2020s, 2050s, and 2080s and hybrids with different growing duration. CERES model

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Model region and climate change impact analysis - Slovakia

Except for solar radiation and temperature conditions, the plant production of Slovak republic is significantly limited by precipitation income during vegetative period. Global warming will cause significant relations in phenology of permanent crops. Onset of vegetative period can occur earlier and conditions of drought occurrence will appear very probably during spring months. Except for temperature and water conditions, there will be influenced also input of solar radiation due to changes of phenology relations. Adaptation strategies can be focused on drought resistant plants (or varieties), irrigation, and changes of sowing term of some annual plants. Direct effect of CO_2 on photosynthesis can reduce yields losses if water is available. Frost during vegetative period can be observed more frequently. Occurrence of new pest and diseases is not described yet.

Danubian Lowland region - CERES

The whole Slovakia lies in moderate climate zone with partial influence of Atlantic Ocean and Eurasian continent. This fact is reflected in yearly precipitation totals 538 mm (1961- 90) and mean air temperature 9,8 °C. The selected region lies on the edge of Danubian Lowland and Zitavska Upland. The research area is located approximately 3 km east from Nitra. The whole area is situated in southwest part of Slovakia with altitude 171m above sea level, at latitude 48°19´ north and at longitude 18°07´east. Climate conditions are favourable for maize growing, so the area is known in Slovakia as a maize agroclimatic zone.

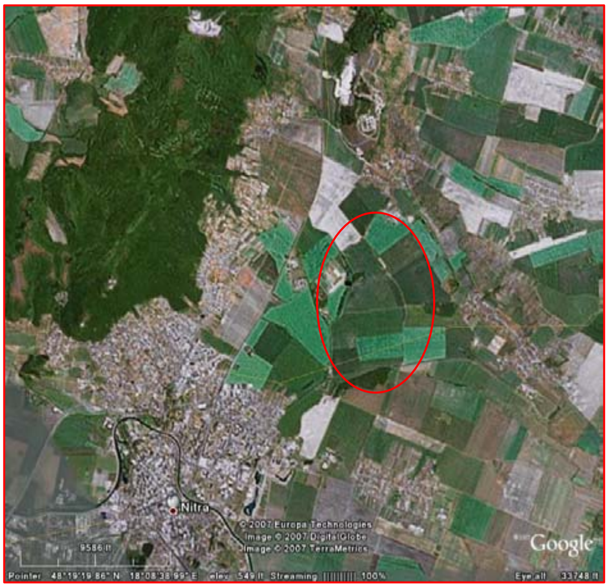

Fig. 1. Nitra- Dolná Malanta (Danubian Lowland) model region

Weather data Meteorological dataset included solar radiation SRAD [MJ/day], maximum daily air temperature TMAX [°C], minimum daily air temperature TMIN [°C], daily amount of precipitation RAIN [mm] and relative sunshine hours SUNH [%]. All these data were measured by conventional weather station situated in the Dolna Malanta region. Nowadays new automatic weather station AWS 200 is in trial service and data from this station are being analyzed and will be used in the future.

Physiological data are represented mostly by crop and cultivar. There was used cultivar LG 23.06 in our case. The cultivar was made by a breeding company Limagrain Genetics Grandes Cultures S.A., France. Its usage is especially in maize and sugar beet agroclimatic productive zones. It is a cultivar with medium short growing season with the FAO number 310. Grain type is a horse's tooth. Plant population for this cultivar was 8 plants per square meter, which is a number very close to recommended 8,5 by a breeding company.

Soil type in Dolna Malanta is loamy clay with these diagnostic layers: Al – depth 0,0 - 0,32 m light brown (10YR 5/4), crumb structure, wet, loose, loamy, uncarbonate, with many roots, number of elements smaller than 0,001 mm reaches 15,56 to 22,17 %, mean pH 5,36.

Bt – depth 0,33 – 0,65 m rusty brown (10YR 5/6), cubic structure, wet, compact, loamy clay, uncarbonate, with few roots, number of elements smaller than 0,001 mm reaches higher values (51,70 – 59,70 %) with mean pH 5,34.

Bt/C – depth 0,66 – 0,85 m yellow brown (10YR 6/4), cubic structure, wet, compact, loamy, uncarbonate , with quartz sand with mean pH 5,97.

C – depth over 0,86 m yellow (10YR 7/6) null structure, wet, compact, carbonate with mean pH 6,73 (Hanes et.al., 1993). All these soil data were built into a soil program Sbuild.

Agrotechnology information includes crop rotation, tillage, irrigation, amount of fertilizers, plant density, day of planting and harvesting. Particular values were changing year to year and are shown in the Table 1.

Year	Planting date	Population density /m^2	Harvest	Tillage date	Previous crop	Fertilizers	Application date, amount of fertilizers in kg/ha
2001	26.4	8	10.10	31.10.00	Pea	KCl	30.10., 20
						1SP	30.10., 15
2002	23.4	8	9.10	19.10.01	Pea	CAN	23.4, 60-70
2003	23.4	8	13.10	21.10.02	Pea	CAN	6.6., 40-50
						1SP	12.5., 44
2004	29.4	8	30.10	27.10.03	Pea	1SP	20.5., 35-40
						CAN	25.4., 60-70

Tab. 1. Agricultural inputs to model (KCl- calcium chloride, 1SP- single super phosphate, CAN- Calcium Ammonium Nitrate solution).

The effect of climate change on cereal crop production

CERES calibration

CERES- Maize model was parameterized by crop yield and length of the vegetative period of maize in Dolna Malanta during time period 2001-2004. Simulated and measured grain yields are very close. Closest results were in 2003, where relative deviation reached 3,47 %. In the other years relative deviation was 3,79 to 10,38 %. That's why the model should probably react correctly to simulated inputs of meteorological elements in condition of changed climate. Some other details have been already published (Samuhel, Šiška, 2006).

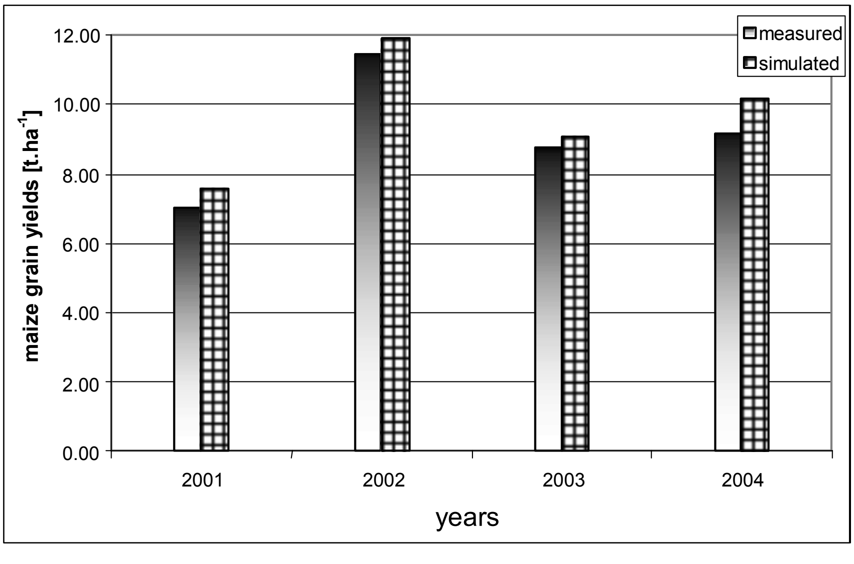

Fig. 3 Measured and simulated maize grain yield [t.ha^{-1}] for 2001-2004 in Nitra –Dolná Malanta

Climate change impact

The figure 4 shows remarkable decrease of maize grain yield in Nitra region that can be probably generalized to the whole Danubian Lowland. Main cause will be especially due to predicted change of climate conditions. Vegetative period shortening will decrease grain yields. Positive effect of CO_2 will probably slightly effect the grain yields. Maize as a plant with C_4 type of photosynthesis react only by about 4% increase of photosynthesis reaction in conditions of $2xCO_2$ (Cure, Ackok 1986).

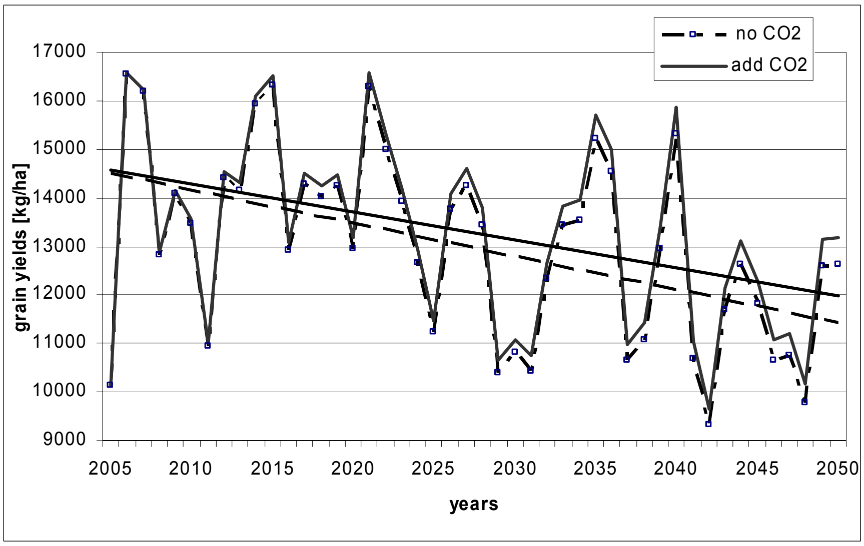

Fig. 4 Maize grain yields (*Zea mays* L.) [$kg.ha^{-1}$] to the year 2050 in Nitra –Dolná Malanta.

In case of direct effect of CO_2 on phytomass creating the decline of grain yield will not be so rapid and grain yields will probably decrease from 14519 $kg.ha^{-1}$ (in conditions of 1xCO2) to 11960 $kg.ha^{-1}$ (17.62 %). If the acclimation effect occurs (no direct effect of CO_2) it is possible to say that decline will reach 11440 $kg.ha^{-1}$ (21.19 %). In simulation was counted with only effect of $1,5xCO_2$ to the year 2050 (500 ppm). Direct effect of CO_2 comparing with acclimation effect (indirect effect of CO_2) increased potential grain yields by 4,54 %. Terms of planting in observed year by supposed development of rain and temperature condition will not be appropriate and can be the reason of the considerable decrease of maize grain yields.

The reason of this study was to test the adjustment of planting date exceeding 10 and 12°C without change on genotype LG 23.06. These results expect decrease of grain yields to 11650 $kg.ha^{-1}$ by date of planting exceeding 10 °C of average daily air temperature respectively 12000 $kg.ha^{-1}$ by temperature12°C. Both series took into account just the effect of changed conditions of atmospheric environment without direct effect of CO_2 on photosynthesis speed.

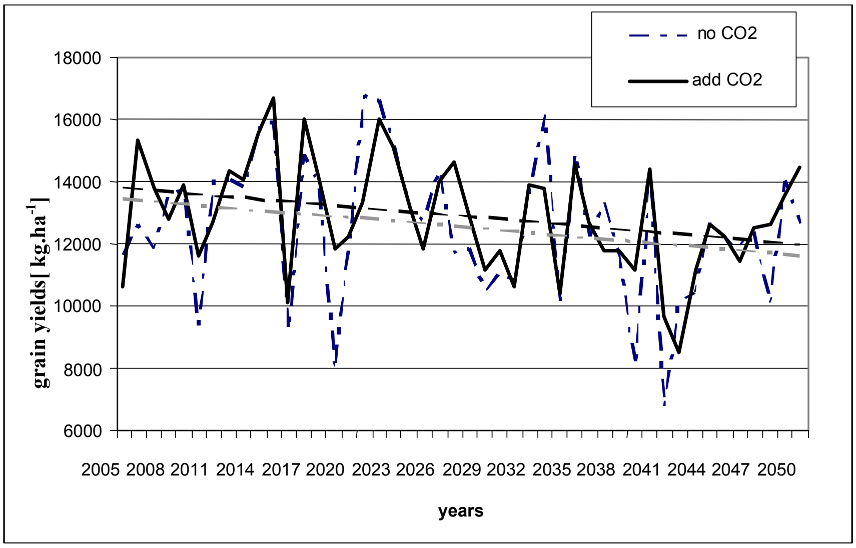

Fig. 5 Maize grain yields (*Zea mays* L.) [kg.ha^{-1}] to the year 2050 in Nitra with the adaptive measure – adjustment of date of planting to days exceeding 10°C (T10) resp. 12 °C (T12) without direct effect of CO_2 on photosynthesis.

Effect of CO_2 on photosynthesis can positively influence height of maize grain yields. Variants with this effect had less rapid decrease of grain yields (12065 kg.ha^{-1}) date of planting exceeding 10°C respectively 12540 kg.ha^{-1} by date of planting with onset of days exceeding 12°C to the year 2050. Better variant in both simulation series seems to be later planting date (by start of days over 12°C – average daily air temperature). Higher values of maize grain yields are probably caused by a fact that vegetative period with onset of days exceeding 12 °C is much less influenced by low air and soil temperatures in early ontogenesis stages. That is the reason why the crop can more effectively absorb photosynthetic active radiation. There is also elimination of late spring freezes in late March and first April weeks.

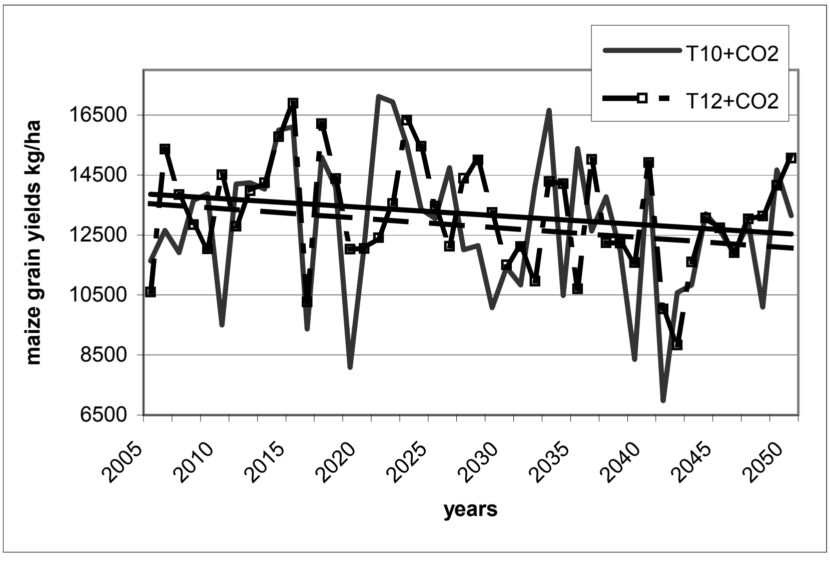

Fig. 6. Maize grains yields (*Zea mays* L.) [kg.ha^{-1}] to the year 2050 in Nitra with using an adaptive measure – direct effect of CO2 to photosynthesis and with adjustment of date of planting by onset of days exceeding 10°C(T10+CO_2) resp. 12 °C (T12+CO_2)

Danubian Lowland and East-Slovakian Lowland regions - DAISY

The research area Milhostov lies in the central part of East-Slovakian Lowland, northwest from small town Trebišov. Altitude of the area is 101 m above sea level. Climatic conditions of the region are more continental (as compared with locality Malanta) with occurrence of frequent extreme meteorological events resulting many times in droughts or floods in past. From the point of view of agroclimatic zonation the area is defined as maize productive zone.

Fig. 7. Milhostov region (East-Slovakian Lowland) model region

The effect of climate change on cereal crop production

DAISY calibration

As the DAISY model originally was developed and validated for Danish conditions it was expected that some problems would appear when transferring the model to Slovak conditions. Especially the crop modules were calibrated after specific cultivars grown in Denmark. Recalibration of the crop modules did not pose major problems primary, due to the availability of good quality data sets.

Nor the calibration of the hydrological processes caused any problems. The large amount of data regarding physical characteristics of the prevailing soil types made it possible to setup detailed soil descriptions and only minor adjustments were necessary in the calibration phase. It was therefore concluded that simulations of the components of the water balance would produce reliable results.

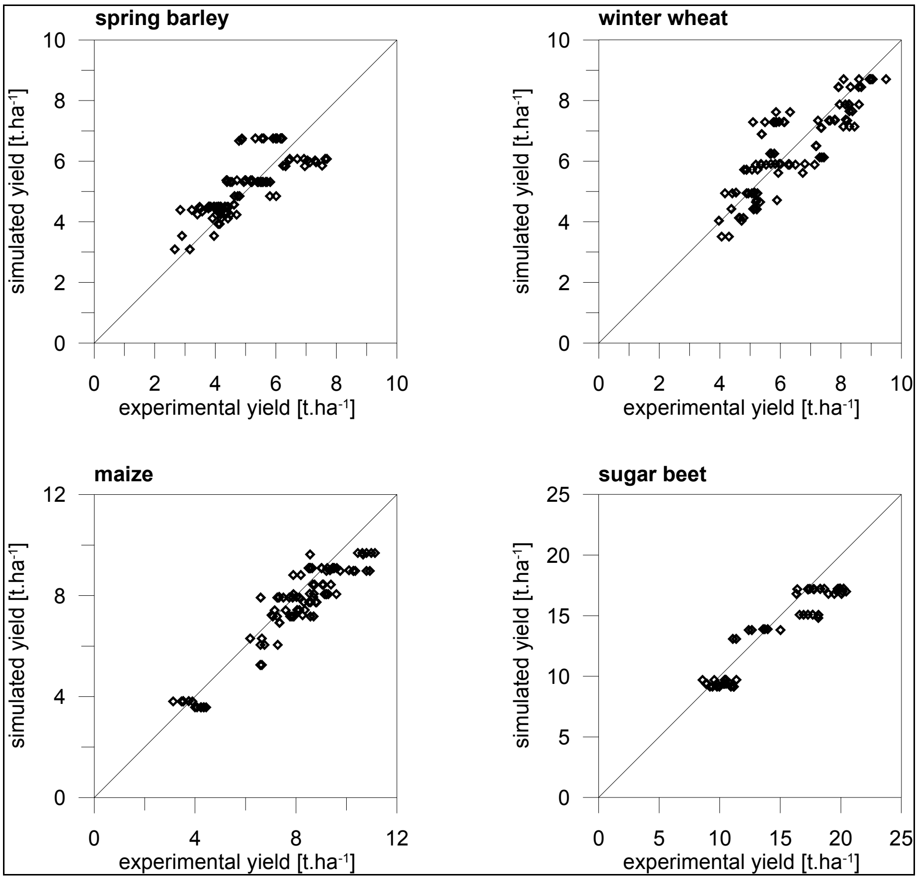

Fig. 8. Simulated and measured yields.

Based on the comparison between measured and simulated dry matter production, nitrogen uptake, nitrate concentrations in soil solution and ammonium and nitrate concentrations in the soil, the overall performance of the model under Slovak conditions was considered satisfactory (DHI et al., 1995).

Crop yields simulated by DAISY were also validated on experimental yields from the field stationary experiment in Most near Bratislava from the years 1973 – 2006. In this experiment were seven irrigated treatments and seven treatments without irrigation with different fertilization by N, P and K. Various crop varieties were grown during this period. Scatter plot of simulated vs. measured yields from this experiment is shown in Fig. 1.

Simulation setup

Analyses were done for different agro-ecological conditions of Slovakia: Danubian and East Slovakian Lowlands and submountain region represented by Liptov basin. Considered crops (spring barley, winter wheat and maize) with 6-years warm up period were arranged into crop rotations on typical soil columns with different fertilisation and irrigation treatments. The simulations were carried out for the reference period (1966 – 1985) and for the climate change emission scenarios SRES A2 and SRES B2, respectively according to the outputs from GCM CCCM (2000). The increasing CO_2 concentration in the atmosphere according to SRES A2 and SRES B2 emission scenarios was a methodical prerequisite. Gradual increase of CO_2 concentration was taken into account.

The effect of CO_2 concentration is not included in the standard DAISY model. Therefore the effect of CO_2 on photosynthesis was simulated via modified light saturated photosynthesis rate and initial light use efficiency.

The water regime was simulated on the level of natural conditions and limited irrigation. The nutritional regime was simulated on the level of natural conditions and limited nitrogen fertilisation.

In simulations with irrigation in an automatic irrigation regime the irrigation doses were applied as soon as available soil water content in the rooting zone decreased below 50 % available moisture capacity (AWC). The frequency of irrigation was restricted to a lower limit of 10 days. This limit was setup because of assumed lack of water sources for irrigation. The beginning and end of irrigation season were defined by growing stages. The aim was not to settle the consumptive water requirements by the crops during the entire vegetation period, but in given important, economic yield forming stages only. Farming practice information was considered to establish the fertilisation regimes.

Winter wheat

In the territory of Slovakia, winter wheat belongs to the crops of strategic importance. The most of Slovak farming entities use to incorporate it into their plant production programmes. The grain yields of winter wheat in Lowlands in the reference period (1966-1985) were in the first place limited by the availability of soil water. In these regions, irrigation considerably contributed to the stabilisation of economic yields in the studied period.

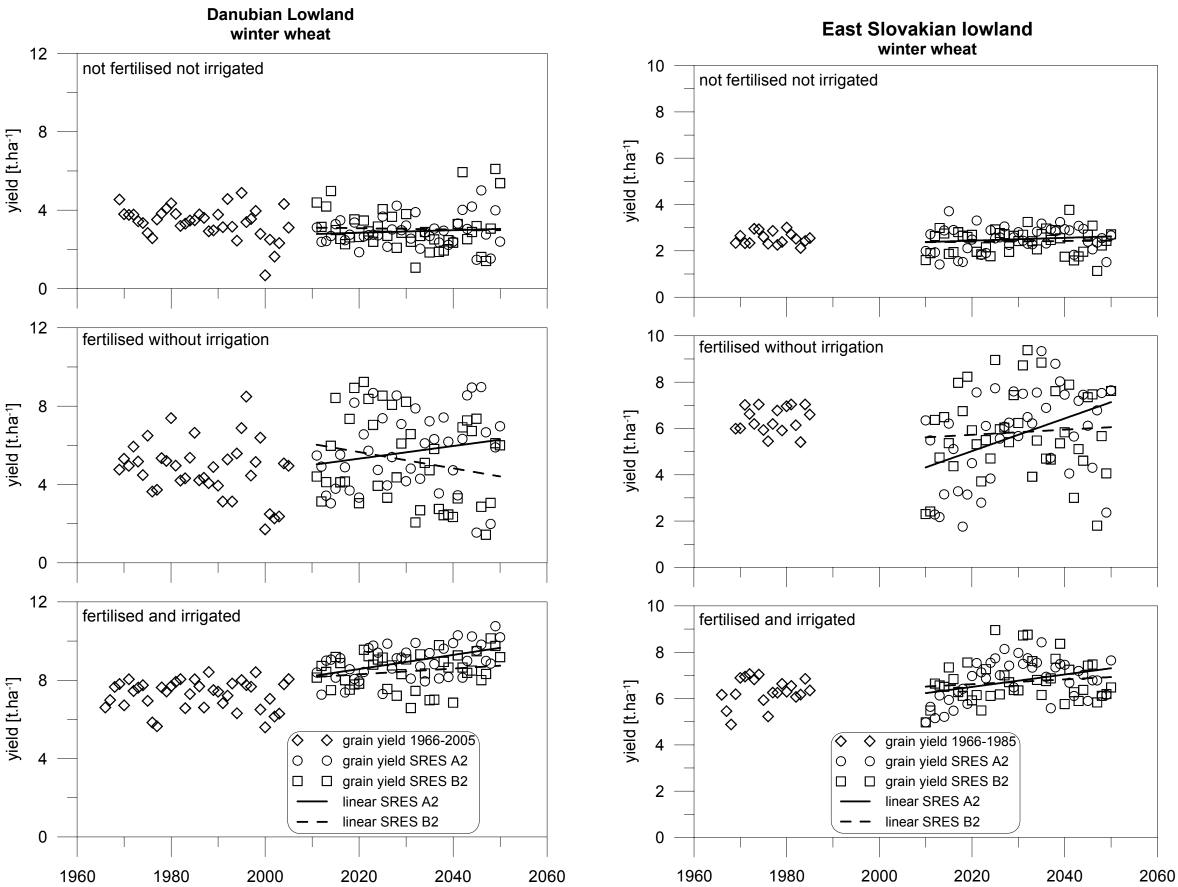

Fig. 9 Simulated grain yields of winter wheat with various fertilisation and irrigation management in Danubian Lowland in the period 1966-2005 and East Slovakian Lowland in the period 1966-1985 according to the scenarios SRES A2 and SRES B2

Simulated top dry matter has increasing tendency in all regions in question according to the scenario SRES A2. On the other hand, simulated top dry matter yield without irrigation in Lowlands is decreasing according to the scenario SRES B2.

Simulated grain yields of winter wheat on irrigated treatments are increasing in all regions according to both scenarios. Simulated grain yields without irrigation are increasing according to the scenario SRES A2. On the other hand, simulated grain yields without irrigation are decreasing according to the scenario SRES B2. A fertilising effect of CO_2 was manifested through increased maximum economic yield values by 20 % - 24 % as compared to the reference period.

The average production effect on economic wheat yields gained by irrigation will decrease. On the other hand, in extraordinary dry years the production efficiency of irrigation increased by 30 – 40 % as compared with the reference period and by the individual scenarios it achieved 4.3 – 4.6 $kg.m^{-3}$ of the supplied irrigation water. The average yield increase owing to the interactive effect of fertilisation and irrigation was by 105 – 110 %. Irrigation was found as a significant factor of yield stability in course of years.

Spring barley

Similarly as by winter wheat the yields of spring barley in Lowlands in the reference period (1966-1985) were in the first place limited by the availability of soil water and it was irrigation that contributed to their stabilisation.

Simulated top dry matter of spring barley was increasing in all regions according to both scenarios except of simulated top dry matter yield without irrigation according to the scenario SRES B2 in Danubian Lowland, which was decreasing.

Simulated grain yields of spring barley on irrigated treatments are increasing in all regions. Simulated grain yields without irrigation are increasing according to the scenario SRES A2. On the other hand, simulated grain yields without irrigation are increasing according to the scenario SRES B2 only on East Slovakian Lowland.

The variability of simulated grain yields of spring barley increased in all the scenarios and in the non irrigated but fertilised treatment by the most. On the contrary it decreased considerably by the irrigated and fertilised treatment.

According to simulation results the average productive effects of irrigation on economic spring barley yields will decrease. On the other hand, the maximum values of production efficiency on spring barley yields in extraordinary dry years will increase by 20 – 25 %.

The interactive effect of irrigation and nutrition on economic yields will be preferred to an effect of one from these factors. Owing to the interactive effect of irrigation and nutrition the simulated yields of spring barley in 2011 – 2030 and in 2031 – 2050 were increased by 85 – 90 % and by 95 – 110 %, respectively.

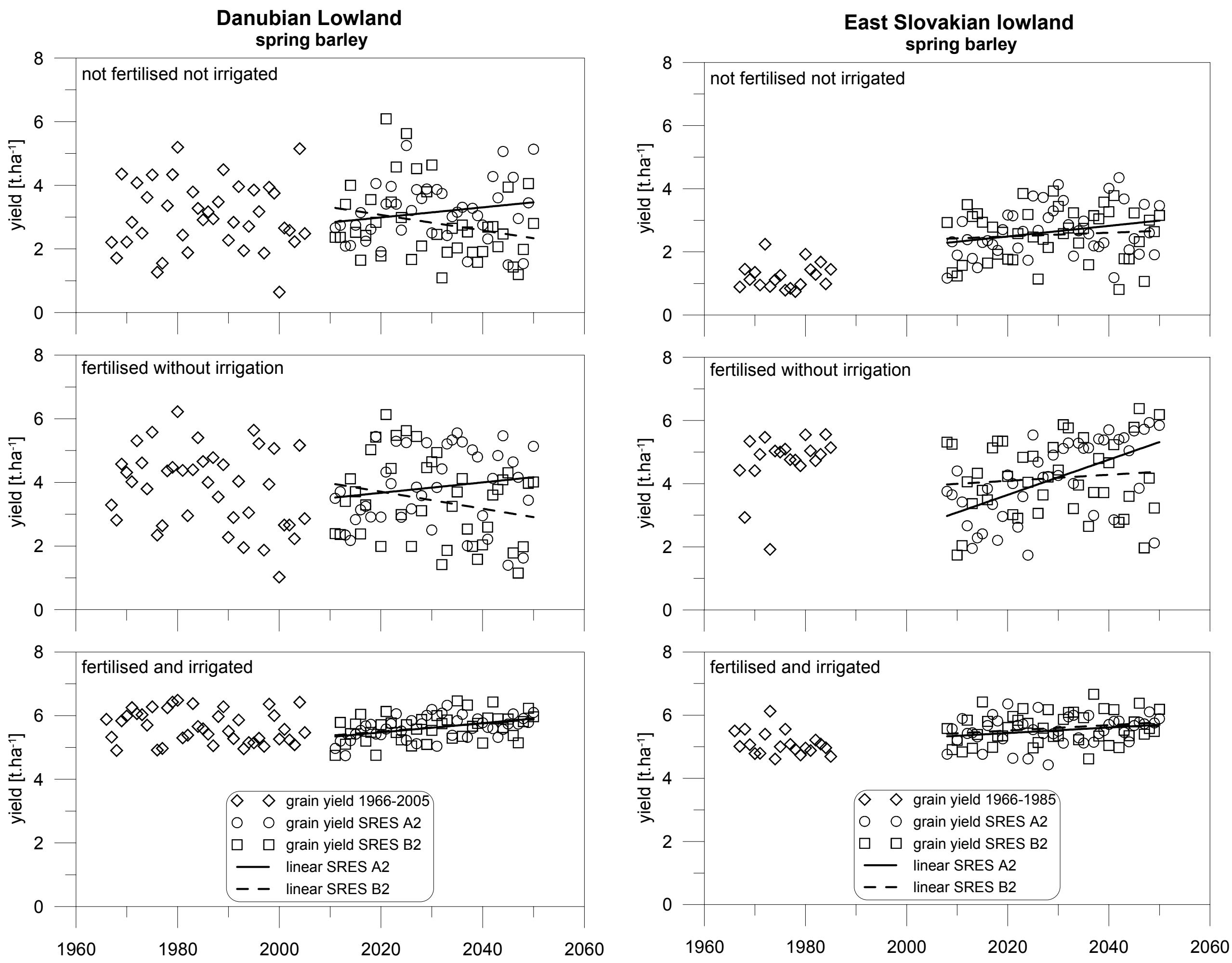

Fig. 10. Simulated grain yields of spring barley with various fertilisation and irrigation management in Danubian Lowland in the period 1966-2005 and in East Slovakian Lowland in the period 1966-1985 according to the scenarios SRES A2 and SRES B2

Maize

In comparison with other crops, maize is a specific one. According to its photosynthesis type it belongs to C_4 species that are less sensitive to changing CO_2 concentrations. In the reference period economic maize yields were in the first place influenced by sufficient water supply and a higher variability in economic maize yields was observed on not irrigated soil. Thus in the reference period the irrigation contributed to the stabilisation of the economic yields. Fertilisation without irrigation had minimum effect on economic yields. Simulated grain yields of maize without irrigation decreased in Danubian Lowland but increased in East Slovakian Lowland. Simulated grain yields of irrigated maize are increasing according to the scenario SRES A2 in both regions and according to the scenario SRES B2 only on East Slovakian Lowland.

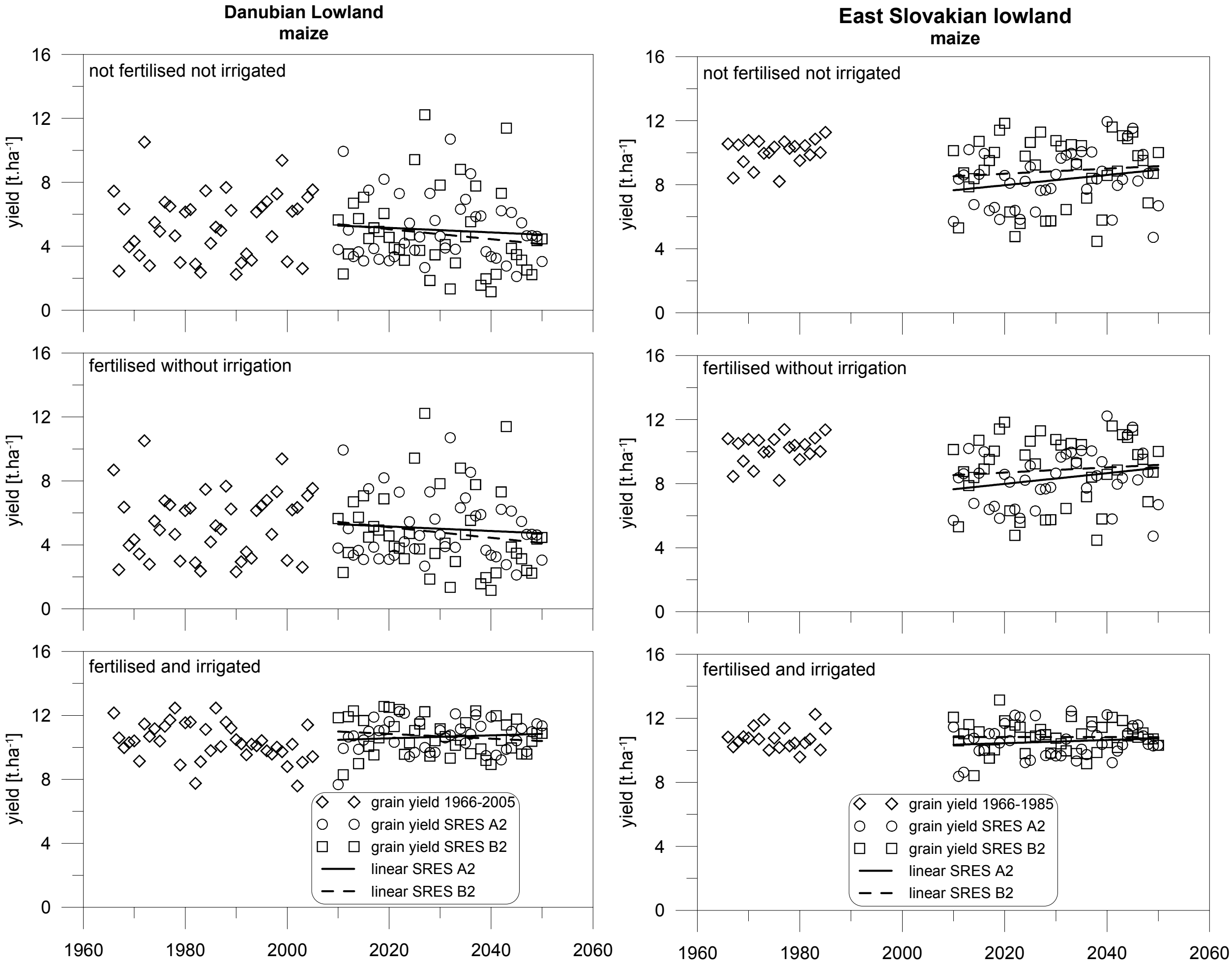

Fig. 11. Simulated grain yields of maize with various fertilisation and irrigation management in Danubian Lowland in the period 1966-2005 and East Slovakian Lowland in the period 1966-1985 according to the scenarios SRES A2 and SRES B2.

Conclusion - CERES

Impact of expected climate change conditions caused by increasing CO_2 concentrations to maize production was tested by combined method using results of regional interpretation of the general atmosphere circulation model CCCM (SRES B2) and DSSAT4 model in conditions of Nitra lying on the edge of Danubian Lowland.

Simulation results in Slovakia show continuous decrease of maize grain yields in both variants with or without direct effect of CO_2 on photosynthesis. In 2^{nd} case there is possibility of considerable decrease of production in this most important productive zone in SR.

Shortening of the vegetative period will decrease grain yields. Positive effect of CO_2 on photosynthesis will probably slightly suppress this negative trend. Anyway grain yields will probably decrease from 14519 $kg.ha^{-1}$ (in conditions of $1xCO_2$) to 11960 $kg.ha^{-1}$ (17.62 %) in time horizon 2050 ($1,5xCO_2$). If the acclimation effect occurres it is possible that yields will decline on 11440 $kg.ha^{-1}$ (-21.19 %).

Within testing adaptive measures for reducing negative impacts of climate change the best solution seems to be the shifting the date of planting determined by days with air temperature exceeding 12 °C. Even to this adaptation it can be expected decrease in grain yields to 12000 $kg.ha^{-1}$ in 2050. On the other hand it is expected higher stability of grain yields, where deviations from average values varied in a range ± 14 %, while in variants with date of planting exceeding 10°C reached ± 18.5 %.

CO_2 effect to photosynthesis is not so strong in C_4 plants in comparing with C_3 plants. That's why maize grain yields influenced by increase CO_2 concentrations to level 500 ppm in combination with adjustment of planting date could increase only by 1.9 % (TS 10+CO_2) or by 2.2 % (TS12+ CO_2).

Due to obtained results possibility of using new cultivars of maize with higher FAO number looks as a good adaptation measure (especially in places where the maize has already been grown) whereas thermal conditions determine the length of main vegetative period and enable growing of this crop. The maize potential to get over periods with lack of precipitation during vegetative period and its wide possibility of usage in crop rotations is an advantage in increasing importance in plant production of Slovakia.

Conclusion - DAISY

The direct yield forming effect of CO_2 was manifested mainly through increased maximum yields that were achieved in years with favourable water and nutritional regimes. The fertilising effect of the atmosphere was more apparent on the increased green matter.

Thanks to the fertilising effect of CO_2 higher yields will be possible, however, higher inputs may be required. On the contrary, insufficient nutrition – mainly on less fertile soils – and lack of water in Lowlands will result in reduced yields.

Simulation results showed an interaction among yield forming considered factors.

All the crops without irrigation showed a higher variability in yields.

Availability of soil water seems to be a limiting factor of crop yields.

Restriction of 10-day irrigation interval allows keep the yields stable. It was already presented that full irrigation leads to rise of the yields (Šiška, Takáč and Igaz, 2004).

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Model regions and climate change impact analysis – Romania

Romania is one of the most rural countries in Europe, with a rural area representing 64% of the country's total surface, more then 12.000 localities and over 48% of the total population. Agriculture is a major component of the Romanian economy representing almost 20% of its Gross Domestic Product. The main crops cultivated are **winter wheat** and **maize**, followed by sunflower, potatoes, sugar-beat and soybeans. In Romania, winter wheat crop covers about 23% of the arable surface planned for field crops, while the maize crop brings Romania on the 9th place in the world as cultivated surface, the mean production/ha representing 59.6% of worldwide mean production (2004).

Romania's climate is temperate-continental with oceanic influences from the west, Mediterranean from the southwest, and continental excessive from the northeast. Yearly mean temperatures vary along the latitude gradient (about 8°C in the north and 11°C in the south) and also on an altitude gradient (2.6°C in the mountain areas and 11.7°C in the plain areas). Yearly rainfall decreases in intensity from west to east, from 800 mm in the northern Tisa Plain to 500-600 mm in the Romanian Plain and to under 400 mm in Dobrogea.

Region of interest - Romania

Drought is one of the major natural processes affecting Romanian agriculture. Forty-eight percent of the agricultural area (14 717.4 thousand ha) is affected by drought, the southeastern and eastern parts of the country being the most affected areas. The drought phenomenon, although without a strict cyclical character, generally shows repeatability at 15-25 years intervals. Within such cycles are extremely dry years, but also short-term interruptions of about 1-3 years with rainfalls above the normal amounts. These interruptions do not modify the general features of the droughty period in respect to severe climate characteristics, as well as to the water resources in the soil, groundwater, and the surface hydrographic network. Average yields of various crops in droughty cycles are only 35-60 percent of the potential yields. In the south and southeastern area of Romania, the complex agricultural drought is a climatic hazard phenomenon inducing the worst consequences ever occurred in agriculture. The intensity, duration, frequency and persistence-related characteristics record maximum values especially in the southern part of the Romanian Plain and Dobrogea, prevailing the extreme droughts (30-35% of the cases), severe droughts (15-25%) and moderate droughts (15-20%) in the sowing-springing period of the winter crops (September-October), and in the hoeing crops critical period (July-August), the number of extreme drought cases varying between 40% and 60% at the level of the southern Romanian Plain, followed by severe drought and moderate drought cases, 20-30% (Mateescu and al., 2003).

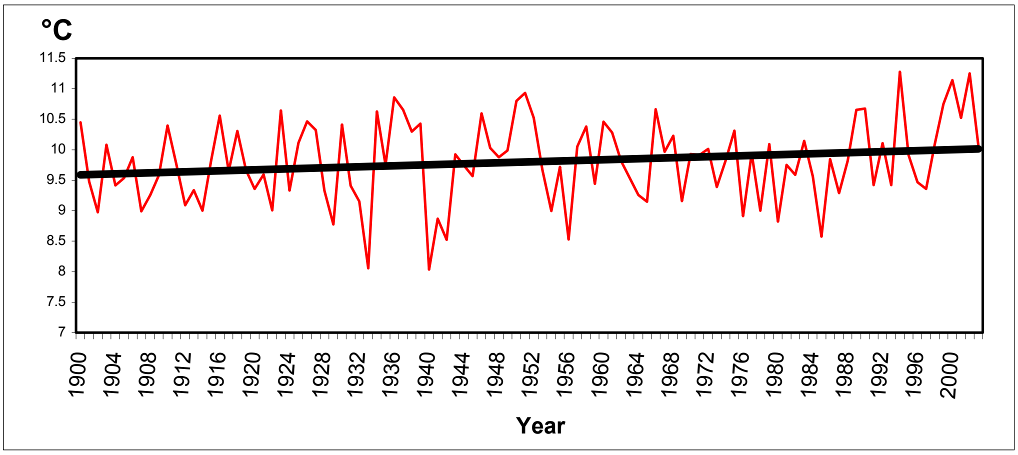


Figure 1. The annual mean air temperature trend in Romania over the period 1900-2000

The analysis in multi-annual fluctuation of the mean annual air temperatures and precipitation stresses upon a significant variability from one year to another during the period 1900-2000, as well as a multi-annual positive trend for mean temperature and negative trend for total annual precipitation (Fig. 1. and 2). The long-term dynamic of these parameters show the availability of a good thermic potential for agriculture, while the hydric potential is limited and decreasing, thus water from precipitation being a limiting factor for field crops production.

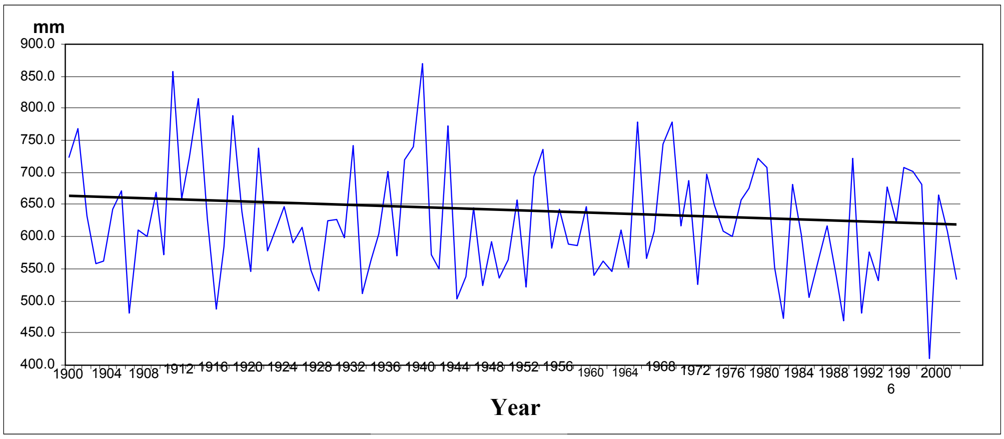


Figure 2. The annual precipitation amount trend in Romania over the period 1900-2000

During the growing season, evapotranspiration is increasing due to higher temperatures and plant development, thus in many years precipitation amounts do not meet crop water requirements. The direct consequence of this unbalance is a gradual decrease of soil available water reserve, inducing hydric stress to plants, many times during particularly important phenological phases like flowering or dry matter accumulation, with negative effects in yield quality and quantity. In this context, it is particularly important to know the multi-annual variability of soil moisture available for plants in order to asses the crop production potential at regional level.

Analysis of the soil water content dynamics from historical data (the period 1970-2000) during the vegetation season, in agricultural areas cultivated with winter wheat and maize showed that south and south-eastern regions of Romania are with very high risk of drought phenomenon and thus are vulnerable to climate change. The next figures (3-4) exemplify the zoning of multi-annual average soil moisture (1961-2000) available for maize crop at August 31st, and zoning of the soil moisture reserves (mc/ha) for the maize crop at 31 August 2000, extremely dry year.

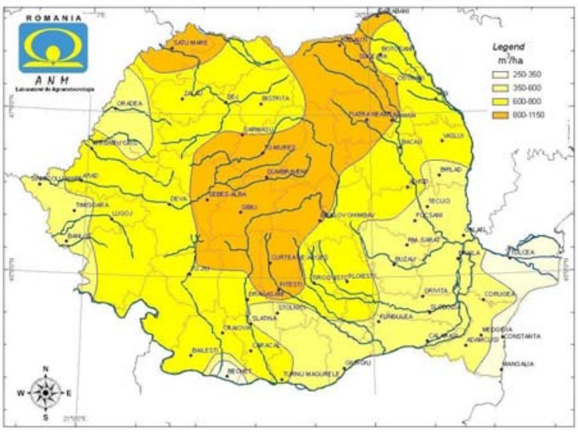


Figure 3. Multi-annual average soil moisture available for maize crop at August 31st

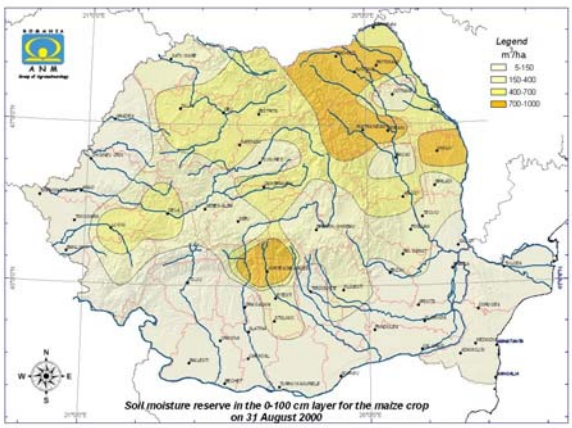


Figure 4. Soil moisture available for maize crop at 31 August 2000, extremely dry year

During the extremely droughty year 2000 record low precipitation amounts resulted in one of the most severe and prolonged drought of the last century. Precipitation deficits as high as 74% produced calamity of the crops on large cultivated surfaces, or extremely low yields – below 700 kg per hectare for maize. Where the winter wheat crops were in irrigated regime, the average yield was 2800 kg per hectare, about a third from the yield potential of the cultivated maize variety.

The stations selected for this project (Table 1 and Fig. 5) are representative for a large and agricultural region, with high importance for crop production, particularly for wheat and maize.

The multi-annual average values (1970-2000) of the in-situ measured soil moisture at specific calendar dates were used to delineate the different classes of soil water availability for plants (Fig. 6). For winter wheat (12 stations), at the end of March, the soil moisture available for plants has satisfactory to optimum values, being generally above 50% of the Available Water Capacity of the soil (AWC), throughout the entire region selected. However, as the plant water requirements are dramatically increasing during the season, the soil water deficits are high in most of the areas and the pedological drought being moderate at the end of May and moderate and severe at the end of June respectively. For the maize crop, the timing of phenological phases is different and the most vulnerable periods are during June-August period. Multi-annual data shows that for the 8 stations selected for this study, at the end of June soil moisture is generally above 50% of the AWC, while at the end of July and August respectively, the maize crops are strongly affected by moderate and severe droughts.

Station	Crop		Relative location in the region	Importance for this study
	Wheat	Maize		
1. Buzau	X	X	Northern half	Pilot Stations
2. Calarasi	X	X	Southern half	
3. Braila	X	X	Northern half	Regional Characterization
4. Ramnicu Sarat	X	X		
5. Pitesti	X			
6. Ploiesti	X	X		
7. Targoviste	X			
8. Fundulea	X	X	Southern half	
9. Giurgiu	X			
10. Oltenita	X	X		
11. Slobozia	X	X		
12. Turnu Magurele	X			

Table 1: List of agro-meteorological stations and monitored crops in Southern Romania

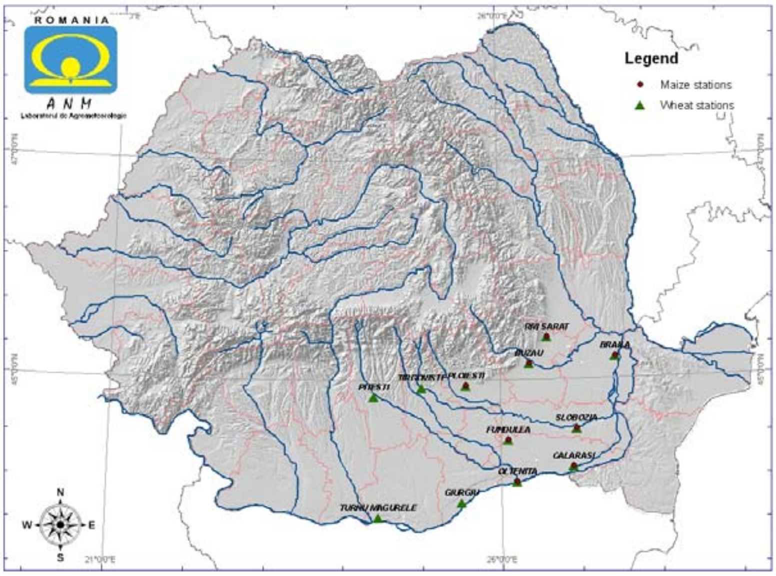


Figure 5. The stations with agrometeorological observation platforms and monitoring program, representative for the area of interest

The data analysed for establishing long-term agro-climatic trends include annual mean air temperature computed from the daily recorded values, during the 1961-2004 interval. The linear trend of this dataset is positive, showing a mean temperature increase of about 1^{o}C for Calarasi meteorological station. Extreme years when mean temperature was significantly above the multi-annual averages of 11.42^{o}C were 1966, 1968, 1975, 1989, 1990, 1994, 1999, 2000, 2001 and 2002 (table 2). Excessively dry years were 1985, 1986, 1990 and 1992, when the annual amount of precipitation was below 50% of optimal plant water requirements.

Year	Mean annual T [^{o}C]	Year	Annual precipitation [mm]
1966	12.30	1962	378 / dry
1968	11,85	1968	407 / dry
1975	11,89	1976	393 / dry
1989	12,13	1982	394 / dry
1990	12,36	1983	383 / dry
1994	**12,77**	1985	349 / excessively dry
1999	12,60	1986	336 / excessively dry
2000	12,73	**1990**	**312 / excessively dry**
2001	12,45	1992	344 / excessively dry
2002	12,27	2000	359 / dry
Multi-annual average 11,42		**Multi-annual average 491,3 / moderately dry**	

Table 2. Extreme years with high values of mean annual temperature and excessively low annual precipitation respectively, during the period 1961-2004.

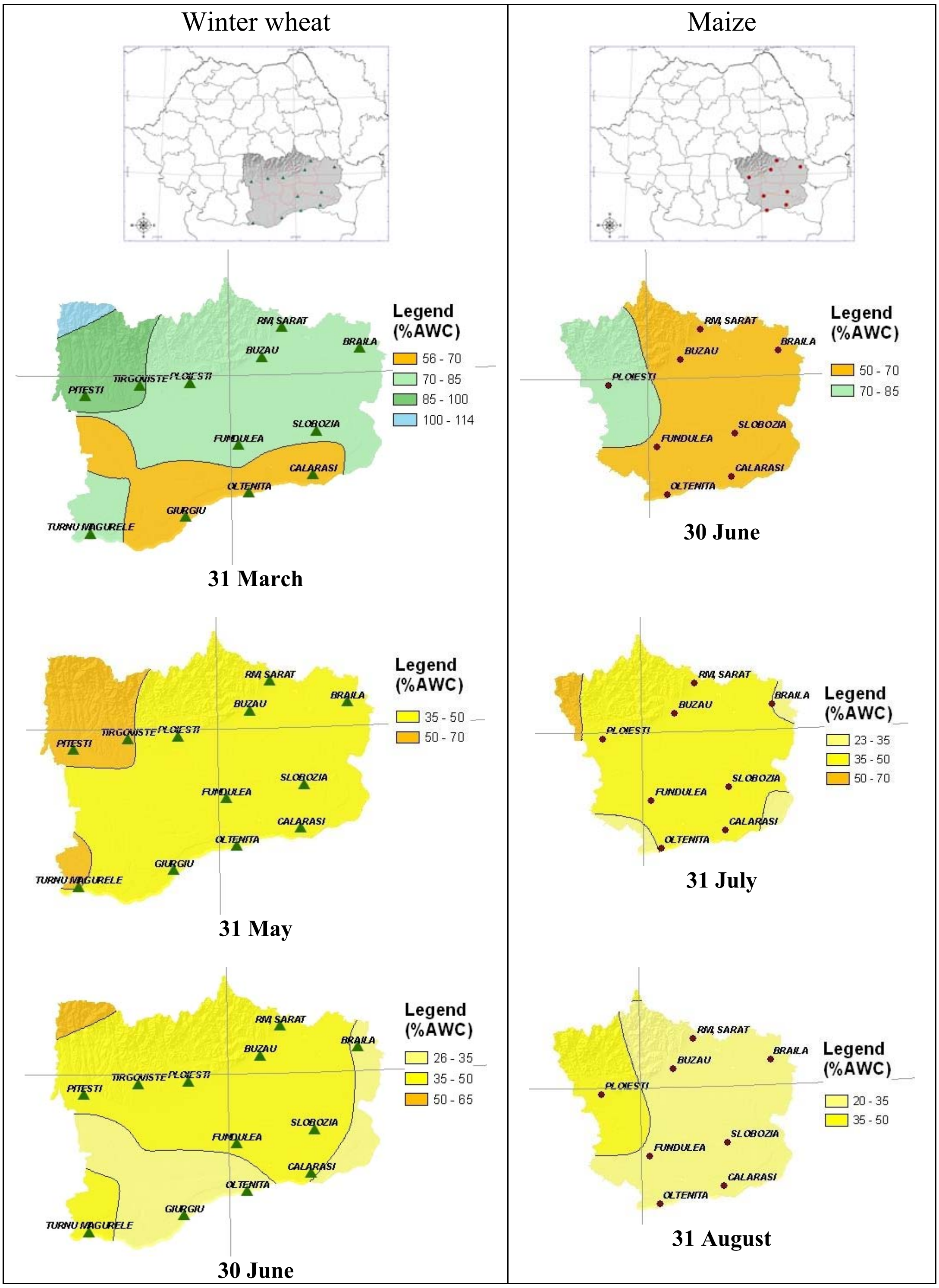


Fig. 6. Multi-annual average (1970-2000) soil moisture spatial variability within the selected region, at specific dates for winter wheat and maize, respectively.

Climate change impacts on cereal crop production

The uncertainty related with weather and climate variability and change is a continuous challenge for many societies, both developing and developed. As with many other countries, Romania must contend with extreme weather and climate events, which result in high variability in crop yields and negative consequences for food supply and the national economy. Both climate variability and climate extremes may increase as a result of global warming. It is becoming more and more evident that food supply in our country will be affected by climate variability and climate change, particularly in regions with high present-day vulnerability and little potential for adaptation.

Yields of grains and other crops could decrease across the southern part of Romania due to increased frequency of drought. While losses may be partially offset by beneficial effects from carbon dioxide, crop production would be further threatened by increases in competition for water and the prevalence of pest and diseases and land losses through desertification. Generally, climate change effects on agricultural crops depend on local conditions of each site, the severity of changes in climate and the direct physiological effects of CO_2 concentration.

An investigation with HadCM3 2020 and 2050 climate scenarios and CERES-Maize model resulted in maize yield decreases of 14% in 2020 and 24% in 2050, compared with the 1961-1990 period, for the pilot station Calarasi. Yield reduction occurs due to shorter grain-filling periods, caused by the higher temperature and lower rainfall. The maize growing season becomes significantly shorter with 10 days in 2020 and with 16 days in 2050 (Fig. 7, 8).

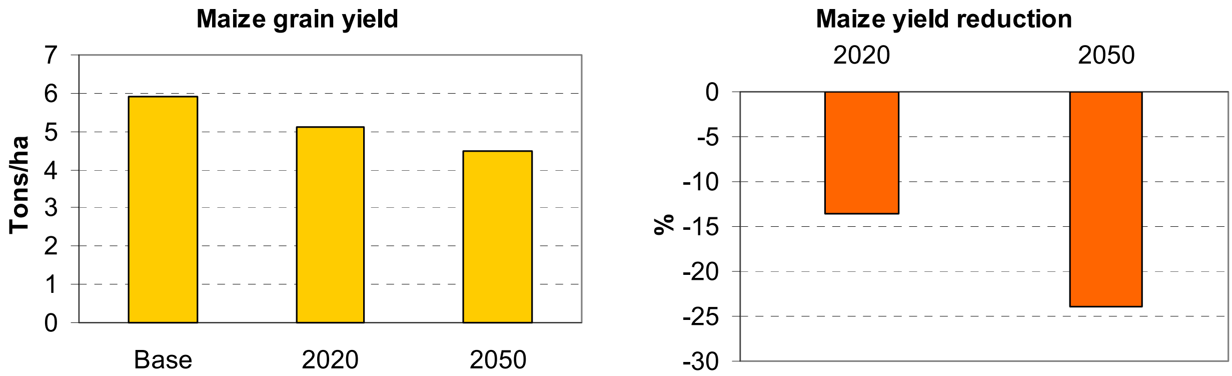


Figure 7. Changes in the maize yield under HadCM3 scenarios (decades 2020 and 2050) as compared with the baseline period (1961-1990), at Calarasi

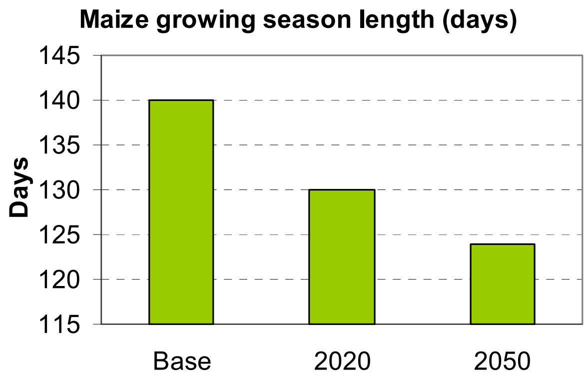


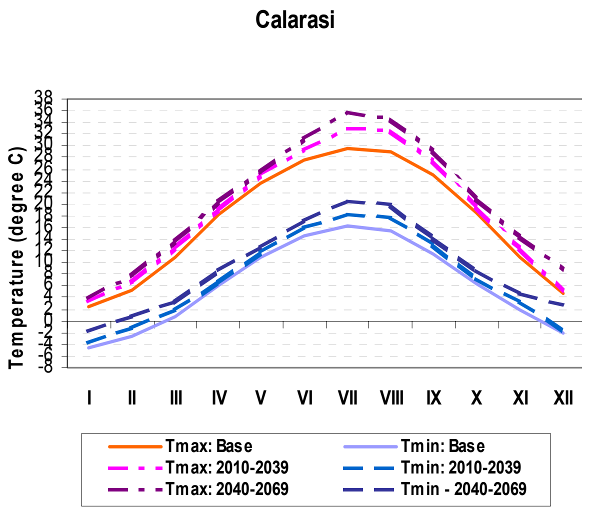
Figure 8. Changes in the growing season length of rainfed maize crop under HadCM3 scenarios (decades 2020 and 2050) as compared with the baseline period (1961-1990), at Calarasi

Agriculture is strongly influenced by the availability of water. Climate change will modify rainfall, evaporation, runoff, and soil moisture storage. Changes in total seasonal precipitation or in its pattern of variability are both important. The occurrence of moisture stress during flowering, pollination, and grain-filling is harmful to most crops and particularly so to maize, soybeans, and wheat. Increased evaporation from the soil and accelerated transpiration in the plants themselves will cause moisture stress; as a result there will be a need to develop crop varieties with greater drought tolerance. The demand for water for irrigation is projected to rise in a warmer climate.

Recent studies on the potential impacts of climate change on the main components of water balance were performed at two sites located in the southern part of Romania, applying the CROPWAT model in conjunction with climate change scenarios derived from global climate model (GCMs). Outputs from global climate model HadCM3 (SRES scenario A2) were used to create climate change scenarios for two-time periods in the future (2010-2039 and 2040-2069), centred on the decades 2020s and 2050s. (Table 3 and Fig. 9).

Site/ Scenario	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	An-nual
2020s	MaxTemp(°C)	0.7	1.5	1.5	0.8	1.2	1.8	3.3	3.4	2.5	1.1	1.6	0.5	**1.7**
	MinTemp(°C)	0.8	1.5	1.1	0.8	0.9	1.3	2.0	2.5	1.7	0.8	1.2	0.6	**1.3**
	Precipit (mm)	2.6	-1	-1	2	-7	-12	-21	-17	-18	-10	18	8	-
2050	MaxTemp(°C)	1.3	2.7	2.7	2.3	1.9	3.8	6.2	5.4	4.2	2.6	3.7	4.0	**3.4**
	MinTemp(°C)	2.7	3.4	2.4	2.6	1.7	2.5	4.3	4.7	3.0	2.2	2.7	4.6	**3.1**
	Precipit (mm)	11	-3	14	15	-7	-34	-35	-21	-19	-14	12	14	-

Table 3. Changes in mean monthly maximum and minimum air temperature (^{o}C), and precipitation (mm/month) for the periods 2010-2039 and 2040-2069 against current climate (baseline 1961-1990), at Calarasi



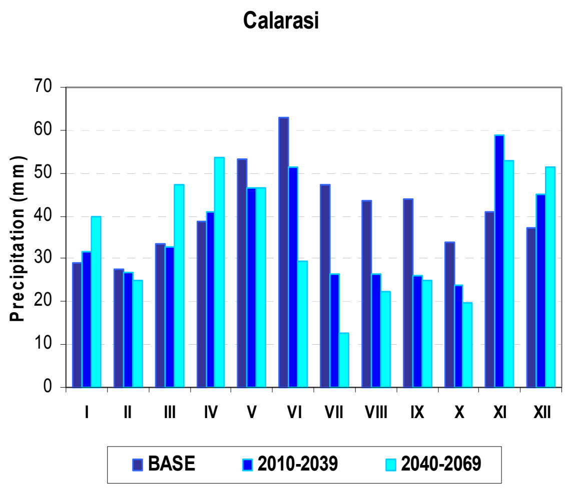


Figure 9. Monthly mean minimum and maximum temperature and precipitation for the baseline climate (1961-1990) and HadCM3 model (periods 2010-2039 & 2040-2069), at Calarasi

The CROPWAT model was run for 30 years, with baseline climate and climate change scenarios. The changes in growing season evapotranspiration, crop water requirements, crop irrigation requirements/soil moisture deficit and changes in percentage of yield reduction were quantified.

Climate change impacts on the water balance components depend on local conditions of each site and the severity of changes in climate. The results obtained in this study has emphasized that changes in climate predicted by the HadCM3 model may have significant negative effects on the main water balance components and maize yield. For example, in 2020s the total soil moisture deficit would be higher by 15-16% sites than during the baseline climate. The soil moisture deficit in the 2050s would be higher by 28% at Calarasi station. The increase of the soil moisture deficit occurs due to higher daily reference evapotranspiration, caused by higher temperatures and lower precipitation inputs during summer.

The occurrence of moisture stress especially during flowering, pollination, and grain-filling is harmful to maize crop, resulting in significantly reduced yield. Under climate change conditions the percentage of yield reduction greatly increases in the both sites and scenarios, up to 60% at Calarasi, due to higher temperatures that shorten the season length, associated with water stress especially during the grain-filling stage (Table 4 and Fig. 10 and 11).

The water availability for maize would decrease due to a combination of increased daily reference evapotranspiration, enhanced losses of soil moisture deficit and decrease in precipitation.

Site	Scenario	SL (day)	ETo (mm)	CWR (mm)	Eff.Prc. (mm)	SMD (mm)	ETc (mm)	Yield Red. (%)
Calarasi	Base	140	652.6	561.5	209.5	356.9	401.8	35.6%
	2020s	-10	-1.4%	-1.3%	-31.2%	15.0%	-16.4%	38.2%
	2050s	-16	-1.5%	-0.8%	-47.6%	27.5%	-24.4%	59.6%

Table 4. CROPWAT model results by climate change scenarios for two sites in the southern region of Romania. SL: season length, ETo: growing season reference evapotranspiration, CWR: growing season crop water requirement, Eff.Prc: growing season effective precipitation, SMD: total soil moisture deficit, ETc: growing season actual crop evapotranspiration, Yield red.: estimated maize yield reduction due to crop stress. Changes from baseline are shown as a percentage.

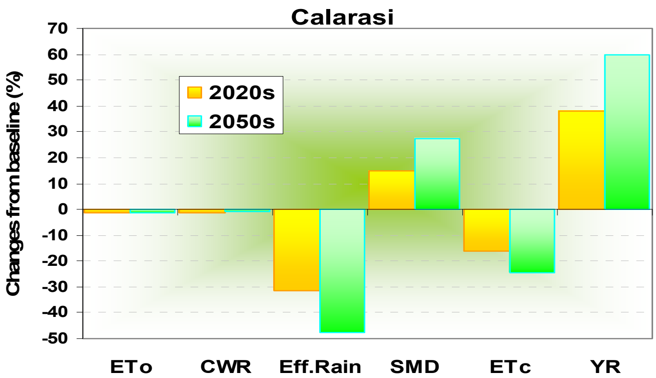


Figure 10. CROPWAT model results by climate change scenarios for Calarasi station in the southern region of Romania. ETo: growing season reference evapotranspiration, CWR: growing season crop water requirement, Eff.Rain: growing season effective rainfall, SMD: total soil moisture deficit, ETc: growing season actual crop evapotranspiration, YR: estimated maize yield reduction due to crop stress. Changes from baseline are shown as a percentage.

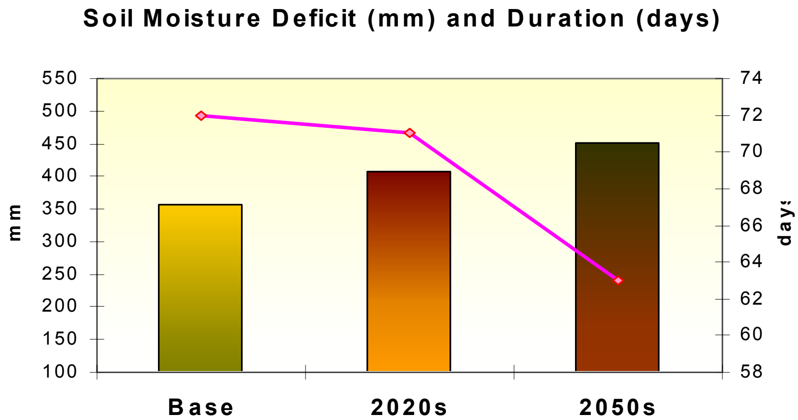


Figure 11. Comparison of the difference in amount (mm) and duration of soil moisture deficit simulated with CROPWAT model in the current climate (base) and the two decades predicted by the HadCM3 model, at Calarasi

Climate change has a major impact in agriculture by affecting the quantity and quality of yields and altering the soil water balance, plant water requirements, and length of vegetation period. However, the combined effects of changes in temperature and precipitation regimes in different climate change scenarios are not yet well understood, thus additional work is required for impact assessment at regional level. Down-scaling the predictions of Global Circulation models (GCM) and taking into account the local conditions of the area of interest will improve the accuracy of crop yield estimations in the new conditions of climate change.

Calibration of CERES and CROPWAT models for the current climate (1961-1990) data will be continued with the rest of the selected stations, for both maize and winter wheat crops, and predictions for the mid-century (2020-2050) and end-century (2070-2100) time-slices will be performed at the two pilot stations, Calarasi and Buzau, using the climatic data provided by the regional models running on climate change scenarios.

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FORESTRY

(NFC - FRI)

Authors:

Tomáš Hlásny, Peter Baláž, Marek Fabrika, Marek Turčáni, Jozef Minďáš, Jaroslav Škvarenina

Methods and models

The effect of climate change on the growth of key forest tree species - growth response analysis

Growth response of tree species to environmental factors is an indicator of the species-environment relationship. It also characterises extend and rate in which the environment drives the potential growth ability of a species. Growth vitality index (GVI) defined as actual/potential tree growth ratio has been used as a key quantity of the approach. This is given as

$$GVI = \frac{h_{act}}{h_{\max}}$$

where GVI is growth vitality index, h_{act} is actual tree height (m) and h_{max} is maximum tree height of a species reachable in a given age (m).

Climatic growth limits of tree species are given by climatic conditions at the marginal locations of their natural distribution. As the temperature in lower altitudes and climatic water balance in higher altitudes are not supposed be limiting, GVI values exceeding the optimum are considered as optimal (GVI response increases/decreases monotonically).

Tree data from forest inventory plots (4x4 km) and climatic data for period 1951-80 were used for the analysis. Selection criteria to involve a tree into the analysis were age>30 years, canopy and above canopy level, no damage influencing the tree height, etc. Average annual air temperature and climatic water balance (IV-IX) has been used as climatic variables. Potential evapotranspiration has been modelled according to FAO (Allen et al. 1998). Both air temperature and climatic water balance have been projected according to CCCM2000.

The growth response function (GRF) has been modelled as quadratic function fitted to the upper 1% of GVI values in each climatic factor class (Fig's. 4, 15). Consequently this has been rescaled to the unit range. Climatic suitability for the growth and occurrence of considered species has been predicted by applying MIN operator to growth response values produced by GVI / temperature and GVI / climatic water balance relationship. GRF have been applied to the so-called normal climate, represented by long-term averages (1951-1980), and on the same climatic variables under CCCM2000. Future climatic conditions have been represented by five 30-years time horizons with the centre in the years 2015, 2030, 2045, 2060 and 2075.

The effect of climate change on the growth of key forest tree species – SIBYLA growth simulator application

SIBYLA growth simulator (Fabrika, Ďurský 2004, 2005ab, Fabrika et al. 2005, described below) was used to model forest production under changing climate. Number of days of vegetation season, mean temperature during vegetation season, year temperature amplitude, and total precipitation during vegetation season are climatic factors the model deals with. These modify height and diameter growth potential, and consequently tree increment. Tree mortality is influenced as well.

Stand models are created as typical stand structures of beech, oak and spruce in lower and mountain sites. Tree values have been generated by data of Slovak yield tables for middle site indices, 30 year (or 45), and critical stand density. The stands have been placed into typical forest vegetation zone, and typical forest eco-regions with appropriate elevation, aspect, and slope. CCCM2000 was used to model beech, spruce and oak production under changed climate. Growth prognosis has been produced with natural development only (natural tree reduction). Forest productions under current and projected climate have been compared.

SIBYLA

Growth model consists of several basic components: generator of stand structure (A), 3-D forest structure model (B), calculation model of the production, ecological and economic forest stand parameters (C), mortality model (D), thinning model (E), competitive model (F) and increment model (G). Algorithms of the major part of the models (D, E, F, G) are based on the principle of the growth simulator SILVA 2.2 (Pretzsch-Kahn 1997). These ones went through the calibration process by means of modification indices or changed parameters. Model (A) was partly revised (generation of the diameters and heights of individual trees in the stand, tree quality generation, generation of the altitude coordinates of the tree bottom position on the GIS grounds) and partial algorithms of the STRUGEN generator of the growth simulator SILVA 2.2 were taken (generation of the horizontal coordinates of the tree position, generation of the crown parameters). Model (C) was completely revised in conformity with algorithms derived for Slovak conditions (calculation of the forest stand production characteristics and forest density characteristics, calculation of the biodiversity indices, calculation of the costs and returns from the forest for the basic harvest and transport activities). Model (B) was also newly developed and it utilises the principles of the generation of the visual forest structure based on the virtual reality. Flowchart of the SIBYLA model is shown in Fig. 1. Information on individual trees (diameters, heights, horizontal and high-altitude positions, heights of the crown setting and crown diameter, tree quality) are the initial input data to the growth simulator. In case of lacking these data, they are generated through the stand structure generator (A). This case often comes into the consideration for the Slovak forest inventory data, where only stand characteristics (mean diameters, mean heights and volume per hectare for individual tree species) are available. Dedicated or generated forest stands are displayed in the form of 3-D model (B) and the production characteristics, forest structure characteristics and economic characteristics are calculated for them by means of calculation model (C). Models in order of mortality model (D), thinning model (E), competitive model (F) and increment model (G) are activated in case, when prognosis to another period is required. Boolean values indicating the status of survival of individual trees in the pointed period (1 .. tree survived, 0 .. tree died) are the results of the mortality model. Boolean values are also resulting from thinning model (E) and value 1 indicates keeping of the tree in the stand and value 0 indicates its removal. Growth reduction factor on the base of the competitive model (F) is calculated afterwards, which depends mainly on competitive pressure of surrounding trees. At the end increment model (G) is applied to every tree, which had passed to another period (both of Boolean values are 1). Diameter and height increments of every tree, which depend on climate and soil site characteristics, are the results of the increment model. These are reduced through the reduction factor coming from previous model (F). New tree diameters and heights are calculated on these bases. Rest tree characteristics as crown parameters are obtained from so-called cross relations. New stand situation is again visualised by model (B) and output stand data are derived from model (C). Model sequence repeats till the end of the prognosis.

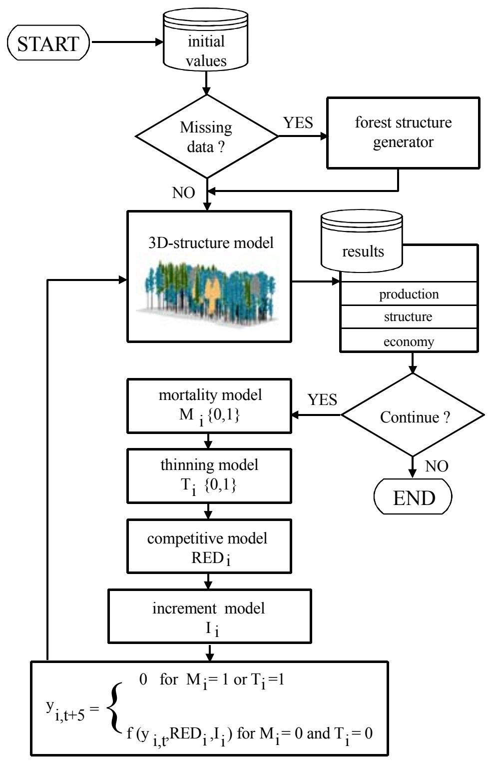

Figure 1. Flowchart of the model SIBYLA

Model regions and climate change impact analysis - Slovakia

Spruce, beech and oak, as dominating and economically the most important tree species, are subject to climate change impacts analysis. Three regions with dominating spruce/beech/oak tree species composition arranged in South-North gradient are proposed for the project (Fig. 2). Intensive elevation and land-use gradient, diametrically different ecological condition, concerned pests and diseases; and forest management techniques characterize the regions.

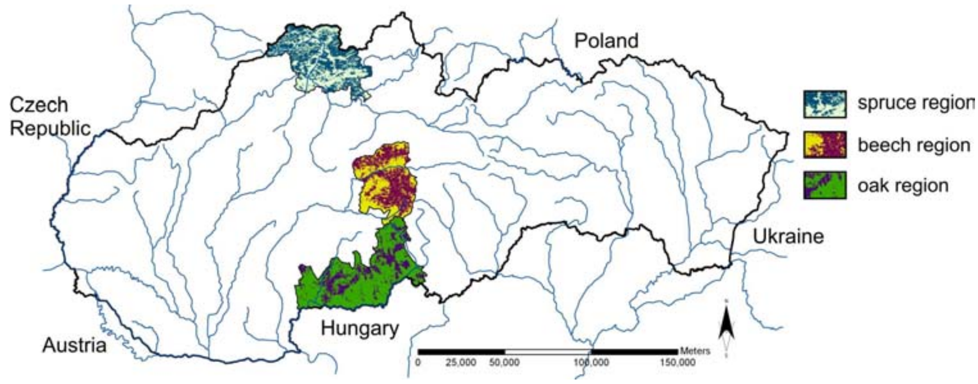

Fig. 2 Model regions with dominating spruce, beech and oak tree species composition

Permanent forest monitoring plots provide detailed data on tree crown conditions, soils, needles and leaves, growth and yield, depositions, air quality, etc. Monitoring cycle varies from continuous measurement of air quality to 2 weeks period in the case depositions, 1 year in the case of crown conditions and growth and yield data (according to BFH, 1998). Daily climatic data are available at climatologic and precipitation stations (Fig's. 3, 12, 17). The data available are daily and monthly records of air temperature (avg, min, max), precipitation totals, air humidity, wind direction and velocity, cloudiness, etc. Detail forestry data by forest compartments and data on sanitary felling due to a range of injurious agent for the period 1996-2006 are provided by national forestry database.

Spruce stands - the Kysuce region

The region lies in the northwest of Slovakia, with extent of 1 434 km^2. It belongs to two climatic regions: moderately warm, very humid, highland subregion of moderately warm region and moderately cold subregion of cold region. It is a part of Slovak – Czech – Poland territory, in the past intensively exposed to air pollution from industrial sources, culminating in 1990. The main forest tree species are spruce (57.5%), beech (21.8%), pine (7.4%), fir (5.3%) and larch (1.9%). Even-age spruce monocultures growing outside the range of natural distribution dominate over the region (Minďáš et al. 2000).

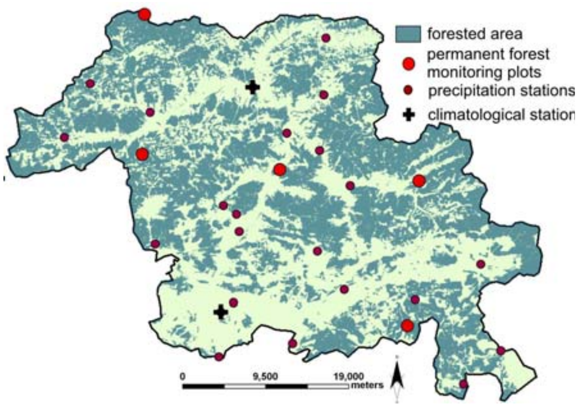

Fig. 3 Forested area and distribution of permanent monitoring plots, precipitation and climatological stations (for reference see Fig. …)

Five permanent forest monitoring plots, two climatologic stations measuring since 1960 and 22 precipitation stations are present in the region (Fig. 3).

Climate change impact on spruce growth – distributional limits and growth response analysis

After applying the selection criteria, as described above, the 3 974 spruce trees at 344 monitoring plots, within the range of spruce natural distribution, were used to model the growth response function (GRF). Growth vitality index (GVI) response to average annual air temperature and to climatic water balance during vegetation season (IV-IX) are given in the Fig. 4. GRF fitted through the upper 1% of the values is given as well.

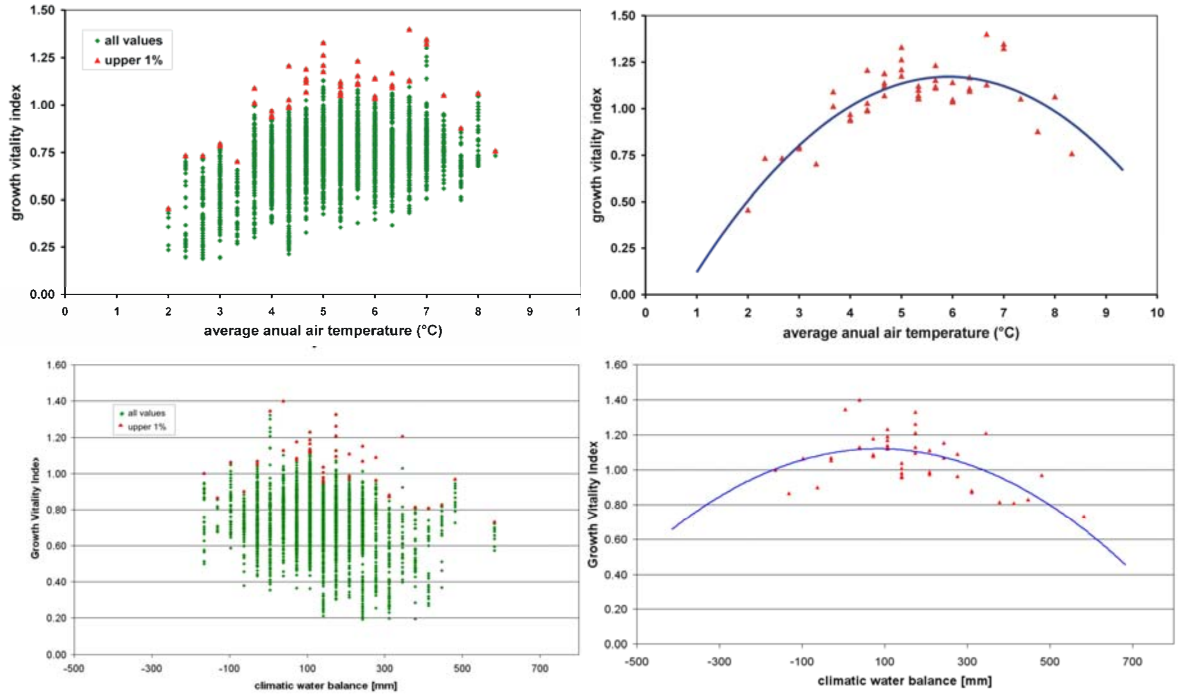

Fig. 4. Quadratic function fitted to the upper 1% values of GVI characterising the species growth-climate relationship.

Parameters of fit of GVI / air temperature: R = 0.807, R^2 = 0.651, residuals normally distributed.

Parameters of fit of GVI / climatic water balance: R = 0.6, R^2 = 0.36, residuals normally distributed (*more detail data will be published soon*).

Applying the functions above to spatial model of given climatic variables and their projections according to CCCM2000 for the period 1951 – 1980, 2030 and 2075 can be seen in the Fig. 5.

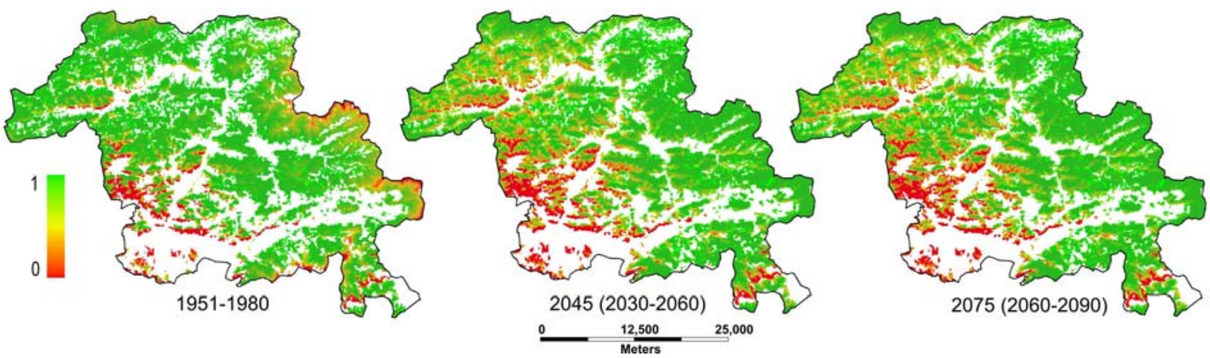

Fig. 5. Spruce growth potential under changing climate in model region

GRF above have also been applied to the entire Slovak Republic territory. Comparison of the extent of area in specified ranges of growth response values under normal climate (1951-1980) and 2075 (2060-2090) time horizon can be seen in the Tab. 1.

Growth response class		Period	
growth resp. value	definition	normal (1950-80)	2075 (2060-90)
-∞ ; 0)	conditions out of natural distribution	55.12 %	71.98 %
<0 ; 0.2)	marginal conditions	3.79 %	2.93 %
<0.2;0.5)	moderately suitable conditions	7.27 %	4.66 %
<0.5;0.9>	suitable conditions	15.88 %	8.04 %
<0.9;1>	optimal conditions	17.94 %	12.38 %

Tab. 1 Changes in suitability of climatic conditions for spruce growth – the comparison between normal climate (1951 – 1980) and time horizon 2075 (2060 – 2090). The table shows the percentage of the total Slovak area in particular growth response classes.

To summarize the analysis, spruce upper climatic limit will practically move out of the Slovak territory. Conditions suitable for species growth almost disappear from lower and middle altitudes; and will be restricted to the mountainous areas only. However, spruce distribution will be there limited by absence of soil.

Climate change impact on spruce production – SIBYLA growth simulator application

Stand models are created as typical stand structures of spruce in lower and mountain sites. Initial stand data for both sites are given in the Tab. 2. Stand models are visualized in the Fig. 6.

Eco-region	**elevation**	**Age**	**stand density**	**Aspect**	**slope**
Poľana	900	30	0,9	South	20°
Species	**Percentage**		**site class**	**yield level**	
Spruce	100%		28	2.2	

Eco-region	**elevation**	**age**	**stand density**	**Aspect**	**slope**
Liptovske Tatry	1300	45	0.9	south-east	25°
Species	**percentage**		**site class**	**yield level**	
Spruce	100%		20	2.2	

Table 2. Initial stand data

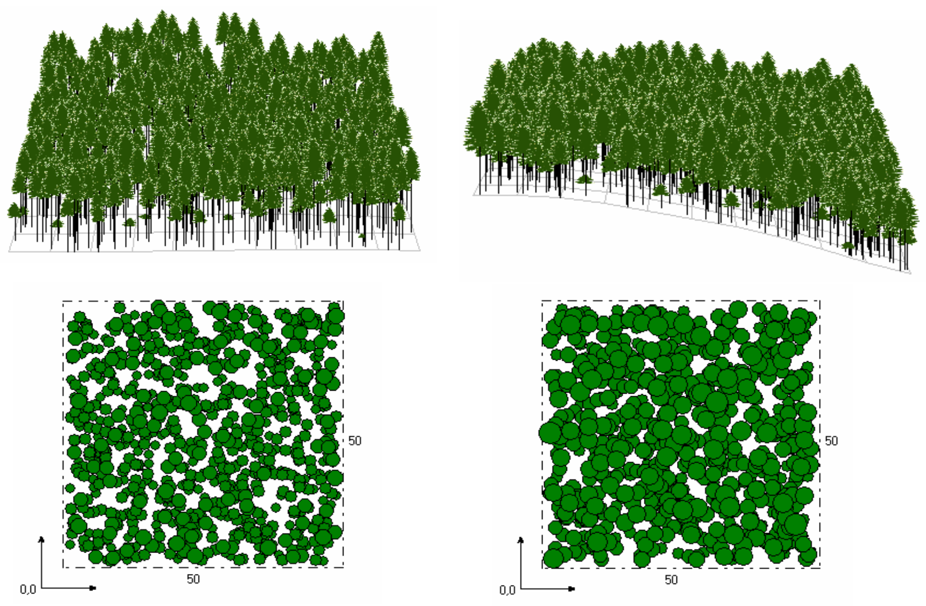

Fig. 6. Stand models visualized

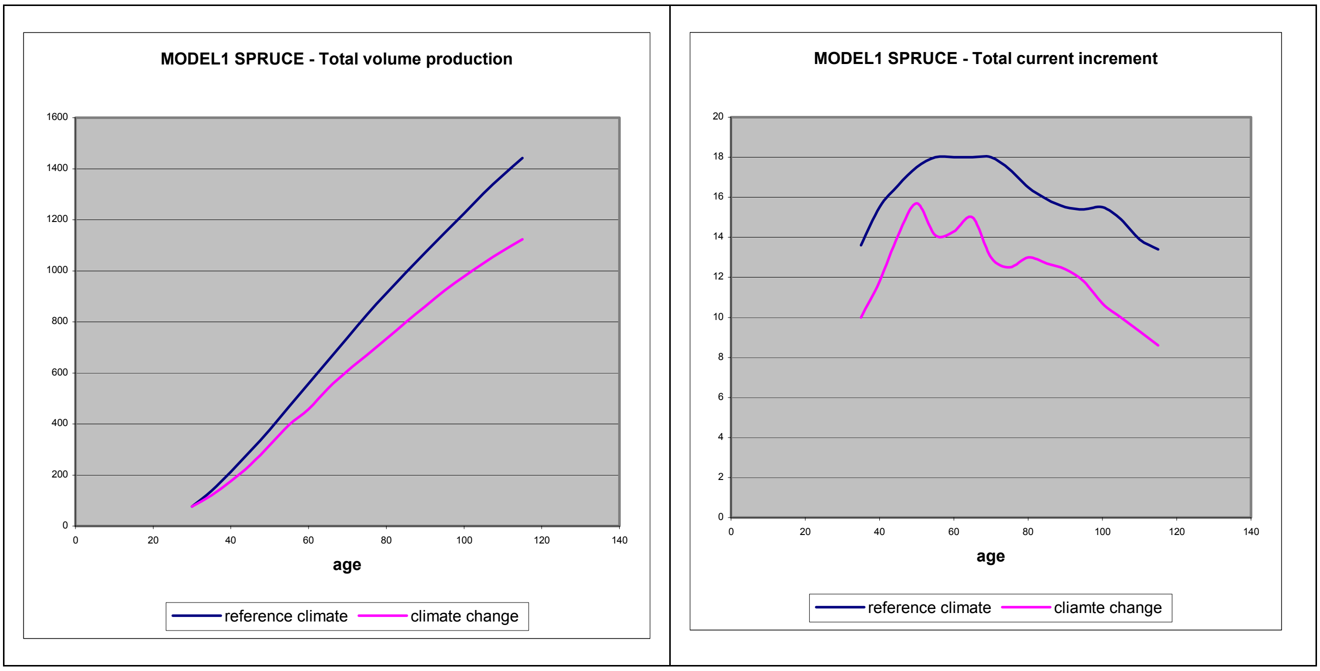

Fig. 7. Stand model: Spruce (lower sites) – Total volume production and total current increment

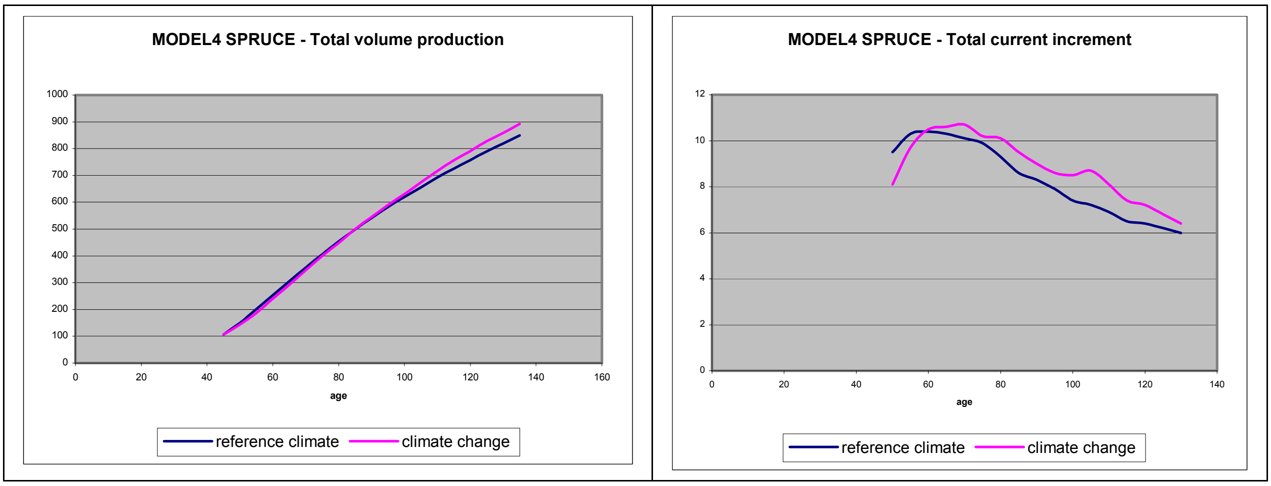

Fig. 8. Stand model: Spruce (lower sites) – Total volume production and total current increment

Simulation has been repeated 30 times and charts (Fig's. 7-8) give mean values of 30 prognosis. Statistical tests of differences between projected climate and referenced climate have been performed. These proved the production of spruce in lower region would be significantly reduced under climate change. The total volume production achieves only 79% in comparison to the production under reference climate. The same pays for the total current increment. Maximal increment under projected climate is 15,8 cubic meter per hectare and year and it is only 88% in comparison to reference climate. Different situation was observed at spruce stands in mountain regions. Projected climate seems to improve living condition for spruce stands there. Total volume production will improve (approximately plus 6%). The same pays for the total current increment. Maximal increment is 3% higher as increment in reference climate. All differences are statistically significant. In conclusion, production of spruce in mountain region will be improved. However, this does not compensate the effect of reduction in other regions.

Climate change impact on dynamics of injurious agents in spruce monocultures

Since the beginning of the 90`s, intensive symptoms of spruce decline are observed in the region, as well as in many other spruce dominated region in Europe. Intensive deforestation due to elevated activity of biotic agents focuses researches and economists on this topic. Climate change and recent occurrence of climate extremes are considered be possible driving forces of decline, however it haven't been analytically proved yet. It is generally supposed, abiotic stressors weaken tree defence system, which is much susceptible to being attacked by biotic agents, or unable recovering after mechanical damages. Some gradations are thought to have been triggered by a combination of insufficient water supply, windthrows, and above-average temperatures. It may be subsequently nurtured by further windthrows, snow breaks and heavy cone production. (Nusslein et al. 2000; Heurich et al. 2001). It is self-evident that windthrowns (as the impact of extreme weather situations) become more frequent since the beginning of the 90s and the amount of wood infested by bark beetles is continuously increasing since the mid of the 80s (Fig. 9, 10, 11). The fact the trees are distributed outside the ranges of their natural distribution, i.e. in unfavourable climatic conditions, emphasizes these processes.

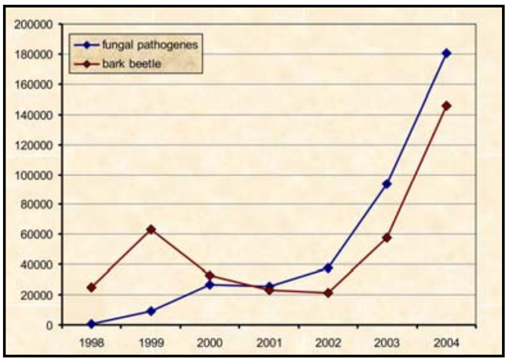

Fig. 9. Amounts of sanitary felling in m^3 due to main biotic damage agents in the region in 1998-2004

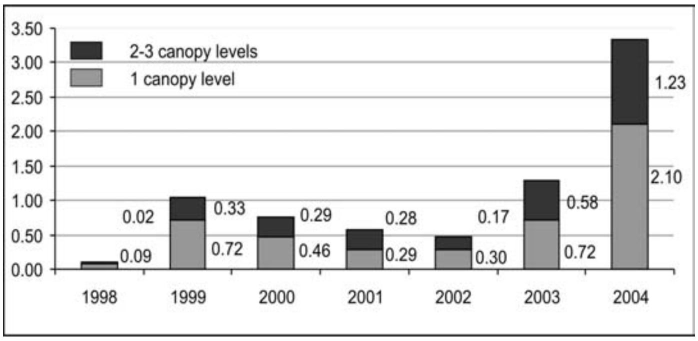

Fig. 10. Intensity of sanitary felling due to bark beetle in different structured stands (m^3/hectar) in 1998-2004

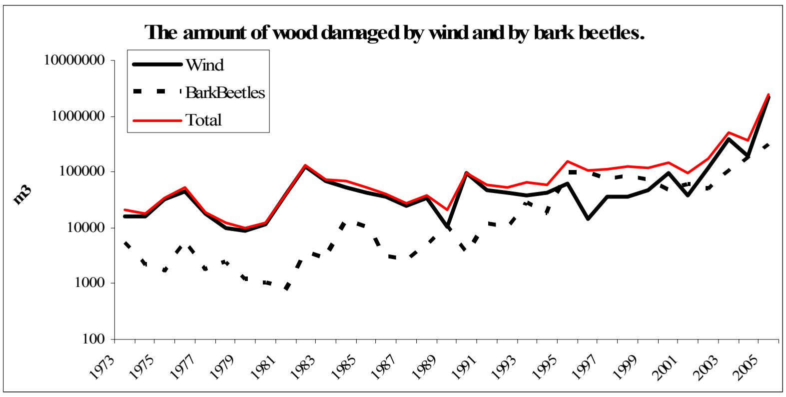

Fig. 11. Trees mortality caused by wind and bark beetles in Slovak part of the Tatra Mountains in the period of 1973-2005.

Predictive modelling of the phenomenon is just in beginnings. Due to unclear and potentially strongly nonlinear relations between variables, the Artificial Neural Networks were used to model predict the decline over the region. Defoliation was used as dependant variable and soil, climate and stand data as the predictors. As part of data was correlated, principal components were used to reduce the amount of input information. No significant relation between the variables has been proved in this stage (Fig. 13). Approximately 40% of the variability of defoliation was explained. None of basic climatic variables improved the prediction significantly, thus applying climate change scenarios on the model cannot be done now.

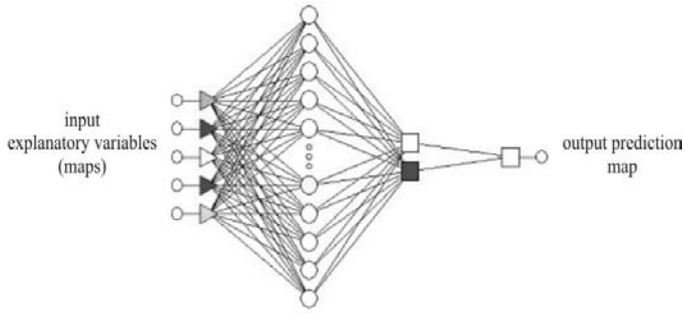

Fig. 12. Structure of neural network used to make a prediction of defoliation

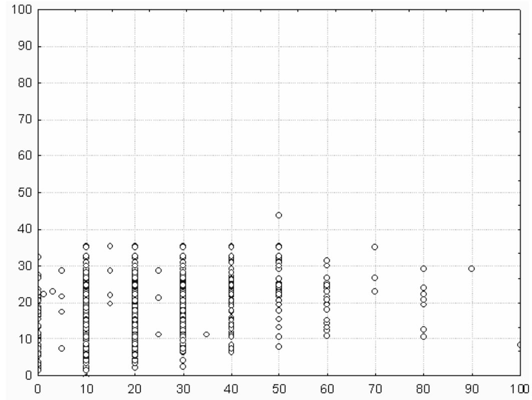

Fig. 13. Predicted vs. observed values of defoliation.

Furthermore, much detailed and complex climatic and stand data will be used as explanatory variables. Also broader range of dependant variables, except defoliation, will be used to train the network. Using large data sets on accidental felling duet to various agents looks very promising and further research focused primarily on that.

Beech stands - the Poľana region

The Poľana region is situated in the central part of Slovakia and covers 1159 km^2. The most of the area belongs to the moderately cold subregion of cold climatic region, highest altitudes reach its cold mountainous subregion and the southern border stretch to the moderately warm subregion of moderately warm climatic region. The model area comprises Biosphere Reserve Poľana and adjacent parts of mountain ranges. Majority of forests in the region is created by beech-dominated stands with large percentage of forests with close-to-natural structure. The main forest tree species are spruce (31%), beech (22%), locust tree (15%), oak (*Quercus petraea s.l.*) (11%), Tureky oak (*Quercus ceris*) (9%), hornbeam (7%) and pine (5%). Four permanent monitoring plots, 3 climatological and 22 precipitation stations are situated in the region (Fig. 14).

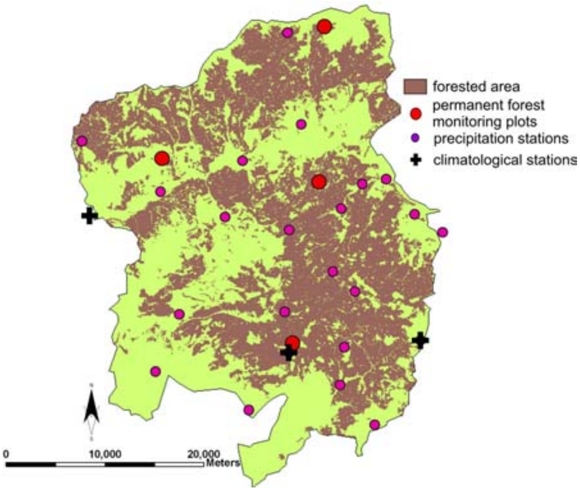

Fig. 14. Forested area and distribution of permanent monitoring plots, precipitation and climatological stations (for reference see Fig. …)

Climate change impact on beech growth – growth response analysis

The 4 064 beech trees at 400 monitoring plots within the range of beech natural distribution were used to model the growth response function. Growth vitality index (GVI) response to climatic gradients and function fitted through the upper 1% of the values (growth response function) can be seen in the Fig. 15.

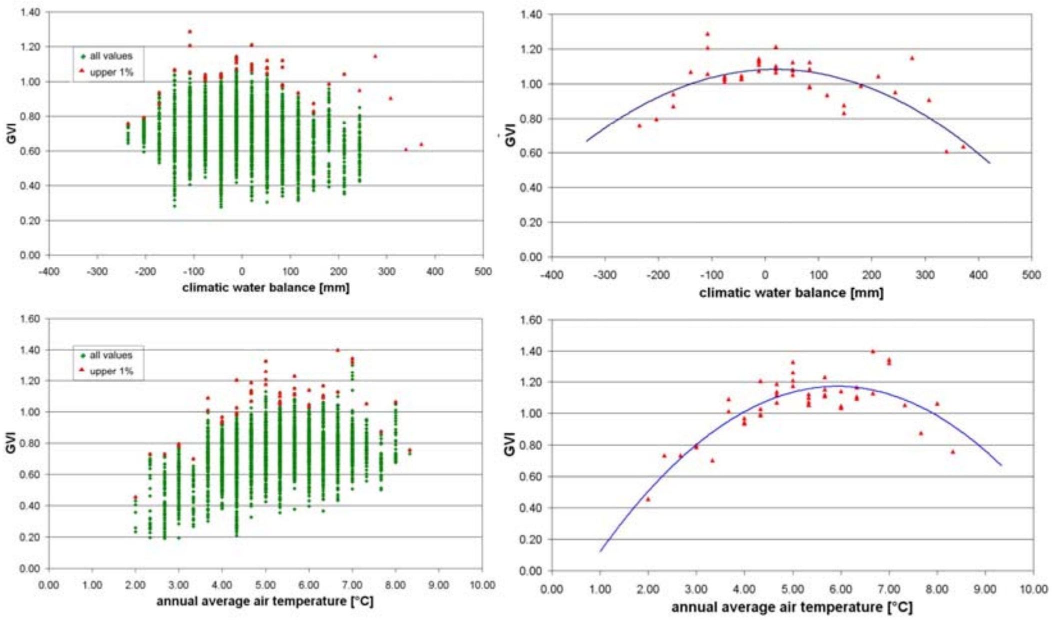

Figure 15. Quadratic function fitted to the upper 1% values of GVI characterising the species growth-climate relationship.

Parameters of fit of GVI / air temperature: R = 0.524, R^2 = 0.68, residuals normally distributed.

Parameters of fit of GCI / clim. water balance: R = 0.789 , R^2 = 0.623, residuals normally distributed.

Applying the functions above to spatial model of given climatic variables and their future projections according to CCCM2000 for the period 1951 – 1980, 2030 and 2075 can be seen in the Fig. 16.

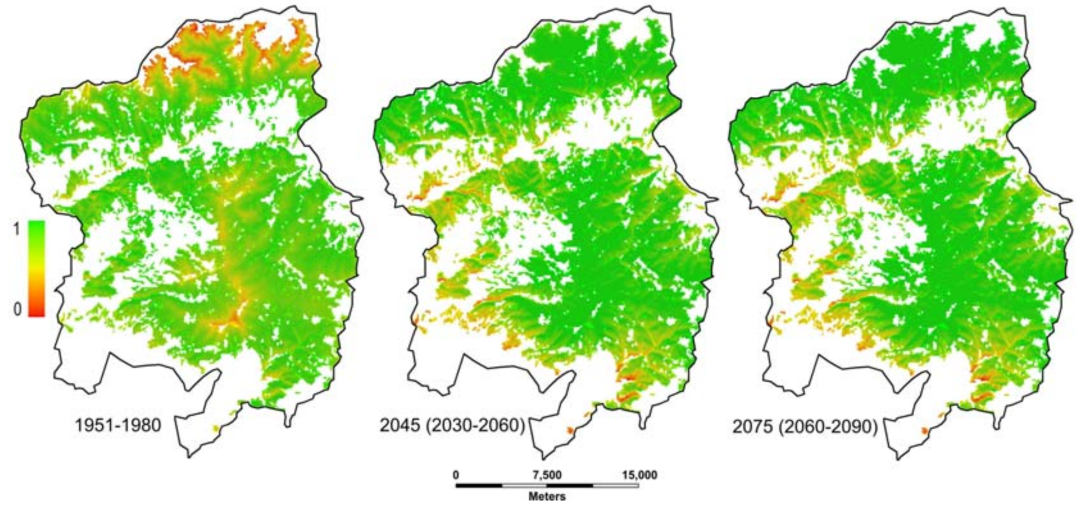

Fig. 16. Beech growth potential under changing climate in model region

GRF above have been applied to all the Slovak Republic territory. As in the case of spruce, significant decrease of the area suitable for beech growth has been noticed under changed climate conditions (CCCM2000). Comparison of the extent of area in specified ranges of growth response values under normal climate (1951-1980) and 2075 (2060-2090) time horizon can be seen in the Tab. 3.

growth response class		**Spruce**	
growth resp. value	**definition**	**normal (1950-80)**	**2075 (2060-90)**
-∞ ; 0)	conditions out of natural distribution	8.16 %	29.56 %
<0 ; 0.2)	marginal conditions	8.44 %	6.82 %
<0.2;0.5)	moderately suitable conditions	14.61 %	11.88 %
<0.5;0.9>	suitable conditions	37.01 %	24.39 %
<0.9;1>	optimal conditions	31.79 %	27.36 %

Tab. 3. Changes in suitability of climatic conditions for beech growth – the comparison between normal climate (1951 – 1980) and time horizon 2075 (2060 – 2090). The table shows the percentage of the total Slovak area in particular growth response classes.

At present, conditions suitable for beech growth cover almost whole Slovak territory, except high mountains and dry lowlands. In 2060-2090 time horizon, these practically disappear from the Pannonian Lowlands at the southern parts of Slovakia. Beech distribution will be restricted to the submountainous and mountainous areas, including mountain valleys. Species upper limit will shift upward to the current upper forest limit zone.

Climate change impact on beech growth – SIBYLA growth simulator application

Stand model is created as typical stand structures of beech. All the remaining parameters were set as in the case of spruce stands (Tab. 4, Fig. 17).

<table>
<tr><th colspan="2">Eco-region</th><th colspan="2">elevation</th><th colspan="2">age</th><th colspan="2">stand density</th><th colspan="2">aspect</th><th colspan="2">slope</th></tr>
<tr><td colspan="2">Zvolenska pahorkatina</td><td colspan="2">400</td><td colspan="2">30</td><td colspan="2">0.8</td><td colspan="2">east</td><td colspan="2">15°</td></tr>
<tr><th colspan="3">species</th><th colspan="3">Percentage</th><th colspan="3">site class</th><th colspan="3">yield level</th></tr>
<tr><td colspan="3">beech</td><td colspan="3">100%</td><td colspan="3">24</td><td colspan="3">2.2</td></tr>
</table>

Tab. 4. Initial stand data

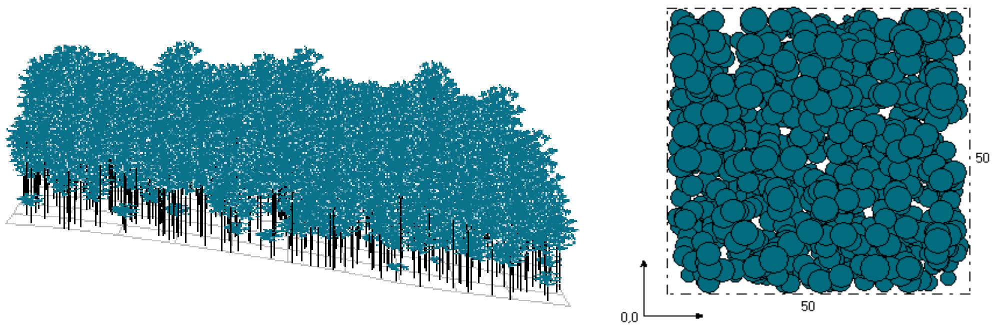

Fig. 17. Stand model visualized

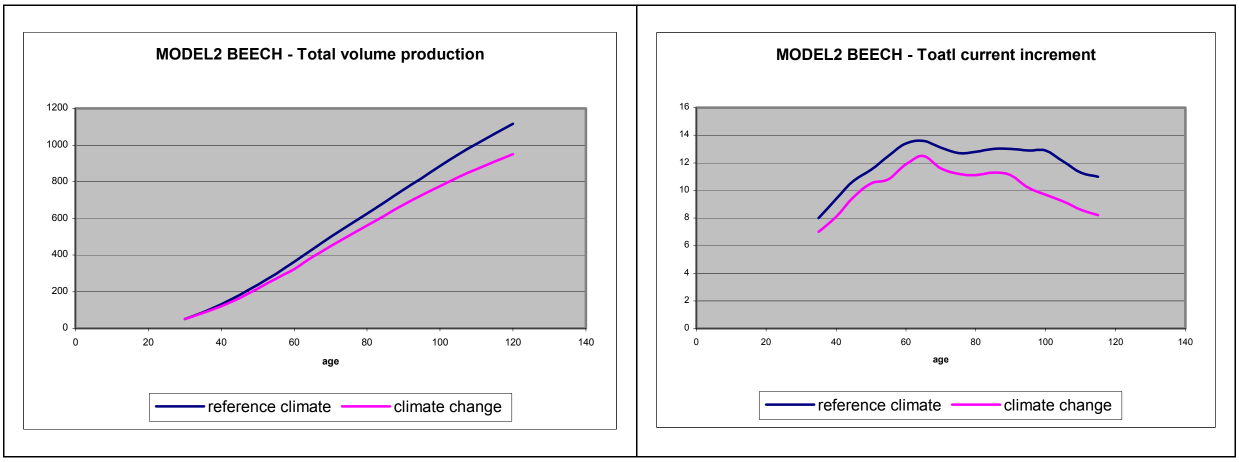

Fig. 18. Stand model: Beech – Total volume production and total current increment

Simulation has been repeated 30 times and presented charts are produced as mean values from 30 prognosis. Statistical tests of differences between projected climate and referenced climate have been performed. As might be seen, beech production in its typical region will bee reduced in comparison to reference climate. Reduction is statistically significant. Total volume production achieves only 86% and maximal total current increment only 94% comparing to reference climate. Total current increment is always lower in projected climate during growth prognosis (Fig's. 17, 18). In conclusion production of beech stands in their natural environments will be significantly reduced under changing climate.

Climate change impact on dynamics of damage agents in beech ecosystems

As the only specific injurious agent, which causes heavy defoliation in beech ecosystems, is *Calliteara pudibunda* (L., 1758), and its gradation cycle lasts 20-30 years (thus there are only 3-4 gradation cycles per century), this will not be studied in the region (Houston 1975). However, there are indications from Hungary, that gypsy moth (*Lymantria dispar*, L. 1758) causes large-scale beech defoliation in years with extremely high seasonal temperature. It has not been recorded in Slovakia yet. Further, we focus on potential changes in outbreak area of gypsy moth in beech stands of the region.

Oak stands - the Krupina plain region

The Krupina plain region lies in the southern part of Slovakia between the Poľana model region and Slovak-Hungarian border. It covers 1 902 km^2. It belongs to almost all subregions of warm climatic region – ranging from warm, dry subregion with mild winter to warm, moderately humid subregion with cold winter. Mainly thermophilic communities with domination of oak species create the forests in the region. The main forest tree species are spruce (26%), beech (22%), oak (*Quercus pubescens, petraea, robur*) (14%), locust tree (10%), oak (*Quercus ceris*) (9%), hornbeam (7%) and pine (5%). Seven permanent monitoring plots, 5 climatological and 27 precipitation stations are situated in the region (Fig. 19).

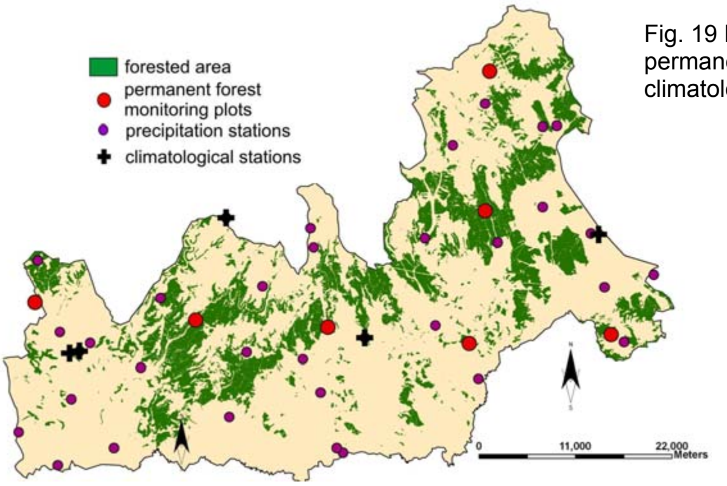

Fig. 19 Forested area and distribution of permanent monitoring plots, precipitation and climatological stations

Climate change impact on oak growth – growth response analysis

Analyses of oak's growth responses to climatic gradients haven't been carried out yet. Only a part of the species ecological amplitude reaches to Slovakia (northern distributional limit), thus additional data from the southern regions are needed. This will be a subject of further research.

Climate change impact on oak growth – SIBYLA growth simulator application

Stand model is created as typical stand structures of oak. Initial stand data are given in the Tab. 5.

Eco-region	elevation	Age	stand density	aspect	Slope
Kosicka kotlina	300	30	0.9	flat	0°

species	Percentage	site class	yield level
oak	100%	24	2.2

Tab. 5. Initial stand data

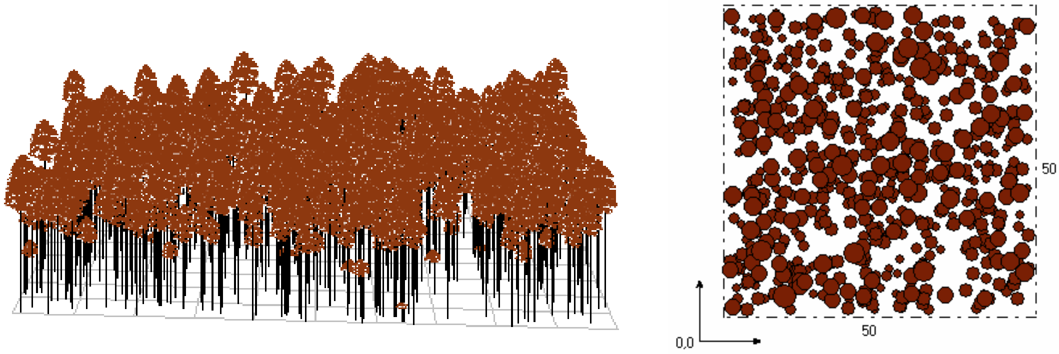

Fig. 20. Stand model visualized

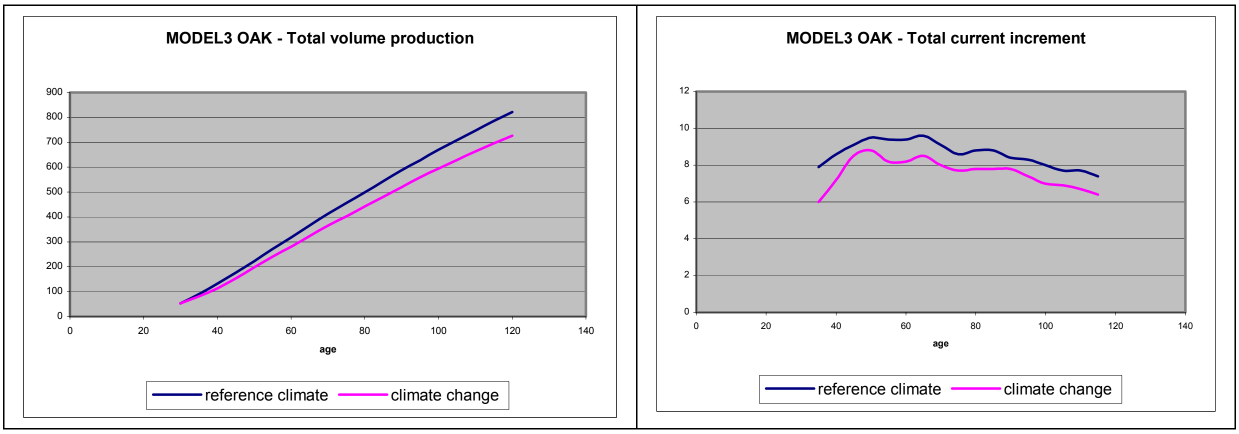

Fig. 21. Stand model: Oak – Total volume production and total current increment

Simulation has been repeated 30 times and presented charts are produced as mean values from 30 prognosis. Statistical tests of differences between projected climate and referenced climate have been performed. As might be seen, oak production in its typical region will bee reduced in comparison to reference climate. Reduction is statistically significant. Total volume production achieves only 88% and maximal total current increment only 91% comparing to reference climate. Total current increment is always lower in projected climate during growth prognosis (Fig. 21). In conclusion production of oak stands in their natural environments will be significantly reduced under changing climate.

Climate change impact on dynamics of damage agents in oak ecosystems

The most important defoliator of oak stands in Slovakia is gypsy moth (*Lymantria dispar*). It is able to defoliate 30-50 thousands hectares during the outbreaks, each 8-10 years. The results of canonical correspondence analysis (CCA) suggested the species is strictly related with several environmental parameters (Fig. 22). The main of them are air temperature and occurrence of *Quercus cerris*. Soil moisture negatively correlates with species abundance.

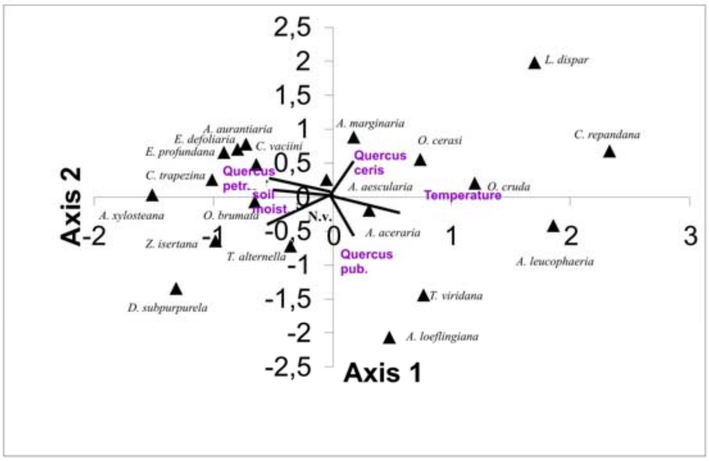

Fig. 22. The result Canonical Correspondence Analysis shows relations of selected defoliators to environmental variables

Using this information, potential outbreak changes under increase of temperature by 1, 2 and 3°C, assuming current distribution of *Quercus cerris*, have been modelled (Fig. 23). The results show that defoliated area may be doubled in periods of high annual temperatures, providing better environmental conditions for the development. Further research will also focus on suitability of alternative food for gypsy moth (e.g. beech, under certain circumstances). The accuracy of predictive models will be tested using the data from several last outbreaks.

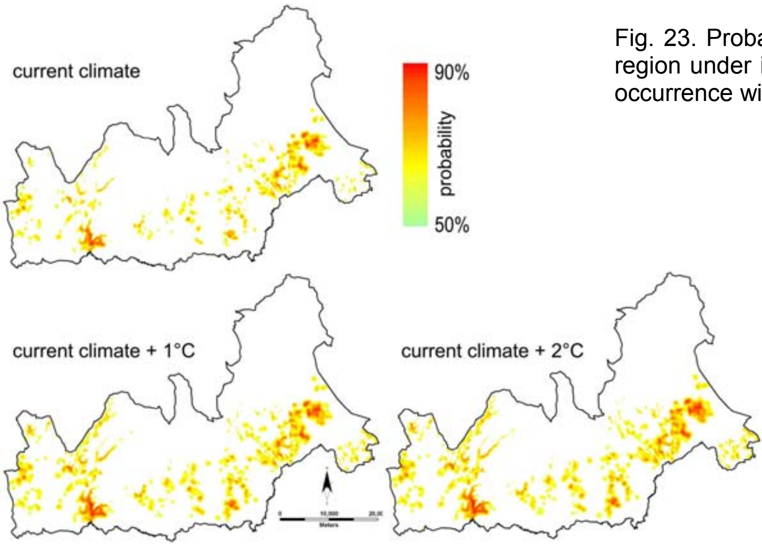

Fig. 23. Probablity of *Lymantria dispar* outbreaks in the region under increasing temperature. Area of outbreaks occurrence with probability above 70%.

prob. > 70%	km^2
t+0	6.27
t+1	11.27
t+2	13.19

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CARBON

(ELU)

Authors: Barcza, Z., Haszpra, L., Bartholy, J., Hidy, D., Pongrácz, R.

Models

Biome- BGC v 4.1.1.

BIOME-BGC is a process based mechanistic biogeochemical model that can be used to simulate carbon, nitrogen and water fluxes of different terrestrial ecosystems (deciduous, evergreen forests, grasslands, shrubs) (Running and Hunt, 1993). Recently some researchers started to evaluate its applicability for croplands. Ecosystem models are becoming more and more sophisticated, and their applicability is restricted in many cases because the values of the required parameters are poorly known or not available at all. BIOME-BGC was the model of choice for us since it is well documented, and most importantly the parameterisation of the model is documented in detail (White et al., 2000).

BIOME-BGC requires three groups of information: daily meteorological data, geomorphologic and soil characteristics, and biome specific eco-physiological parameters. If the model is calibrated against eddy covariance measurements, the eco-physiological parameters may be considered constant (or at least most of the parameters can be treated as constant) so that only daily meteorology data is needed to simulate the future behaviour of the ecosystems. The minimum data requirement to use BIOME-BGC is daily maximum and minimum temperature, and daily sum of precipitation. All other data can be calculated with additional software.

Currently we are about to perform the calibration of the BIOME-BGC model using our eddy covariance based carbon exchange data. We use Bayesian approach to calibrate the model for the grassland, and maximum likelihood method to do the same for the mixed agricultural land (Tomelleri et al., 2005; Hidy et al., 2006). Once the model is calibrated it can be used with climate scenario data for the region. The impact studies will highlight the possible relationship between the climate change and the carbon dynamics of the region.

Model regions and climate change impacts analysis - Hungary

Vas County, Western Hungary

Vas is an administrative county of Hungary. Vas County is a NUTS level 3 region (code HU222), which belongs to the Western Transdanubia NUTS2 region, that is part of the Transdanubia NUTS1 region. Vas County lies in the western part of Hungary. It is situated close to the Alps and shares borders with Slovenia and Austria. Vas County's area is 333,600 ha, its minimum altitude is 139 m, the maximum altitude is 882 m. Its climate is temperate, the climate type is Cfb according to the Koeppen-Classification system.

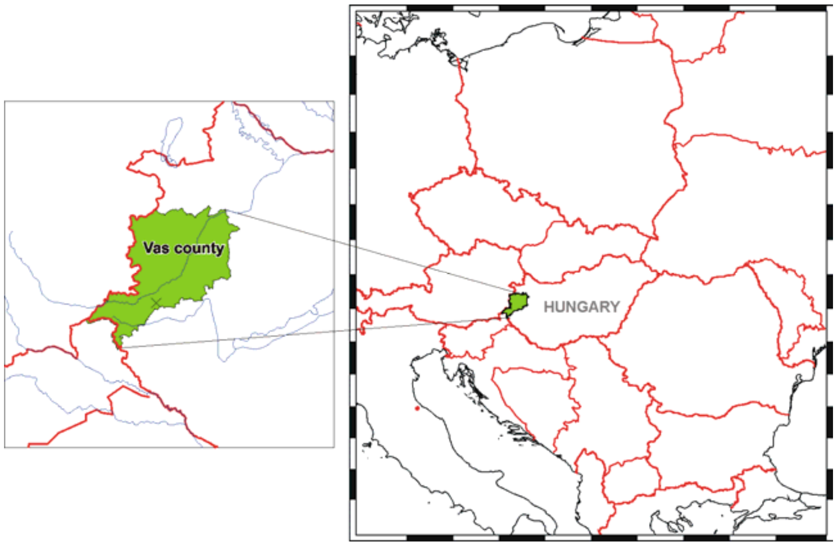

Figure 1. Central-Eastern European region, and the location of Vas county (marked by green). In the left map the X symbol marks the Hegyhátsál measurement site (see below).

The primary reason to select Vas County, as the Hungarian target area of future impact studies, was the presence of the Hegyhátsál measurement site (46°57'N, 16°39'E, 248 m a. s. l.). The Hegyhátsál tall tower site is the centre of many greenhouse gas related programmes in Hungary (http://nimbus.elte.hu/hhs). The measurement site is operated jointly by the Eötvös Loránd University and the Hungarian Meteorological Service, and it belongs to the CARBOEUROPE cluster (http://www.carboeurope.org). Using the available high quality, direct measurement data we can calibrate and validate a process-based ecosystem model (BIOME-BGC) which can be used to simulate the present and future carbon dynamics of grasslands and mixed croplands (Tomelleri et al., 2005; Hidy et al., 2006). Since the carbon dynamics of agricultural crops is closely related to their productivity, the results can be compared to agricultural crop yield data to estimate climate change impact on agricultural production.

Another reason to select Vas County was that it is one of the regions inside Hungary, which may be highly vulnerable in case of global climate change. According to the various climate data observed by the Hungarian Meteorological Service, annual precipitation amount has decreased by more than 20% since 1951, while annual mean temperature has increased by about 1.2-1.3°C between 1975 and 2004. Thus, climate change related studies and estimation of future trends are of great importance in this subregion as well, as in the entire Central/Eastern European region.

Relevant research running in Vas County

The television/radio transmitter tower (owned by Antenna Hungária Corp.) at Hegyhátsál is equipped with instruments to measure the atmospheric mixing ratio of different greenhouse gases (CO_2, CH_4, N_2O, SF_6) (Haszpra, 1999; Haszpra et al., 2001). Since 1997 the carbon dioxide exchange between the biosphere and the atmosphere has also been measured (Barcza, 2001; Haszpra et al., 2005). In this measurement programme we use the so-called eddy covariance technique (Baldocchi, 2003) to calculate the amount of carbon that is taken up or released by the vegetation in hourly, daily, monthly and annual time step. The measurement represents the carbon dynamics of the mixed agricultural region around the tall tower (Haszpra et al., 2005). The tower is surrounded by a regionally typical mixture of agricultural fields (mostly crops of annually changing types) and forest patches. During 1999 and 2000 the CO_2 exchange of the semi-natural grassland that is located around the transmitter tower was also measured (Barcza et al., 2003). This measurement was restarted in autumn, 2006, and it is in operation now. The measurement setup is unique in Central Europe since we have two independent eddy covariance systems measuring the carbon exchange of two different ecosystems.

Data

We have direct carbon exchange data (net ecosystem exchange of carbon, NEE) since 1997 (year 2000 is completely missing due to instrument malfunction) based on the large scale eddy covariance system (mixed agricultural land, regional data). We also have NEE data for the grassland from 1999 to 2000, and since autumn, 2006. We have meteorology data for Hegyhátsál, but precipitation is taken from a nearby meteorological station because there is no precipitation measurement at Hegyhátsál. We also have winter wheat and maize yield data for Vas county from 1986 to 2005 by courtesy of the Hungarian Central Statistical Office. For modelling, historical meteorology data are needed. For that purpose we use CRU TS 1.2 data[1] (10 minute resolution gridded dataset, monthly mean temperature, daily temperature range, precipitation;). We use weather generator to create daily data based on the monthly means.

Climate change impact on carbon cycle

Due to the length of the based on the Hegyhátsál carbon cycle related measurements, it is possible to analyze the dependence of the carbon budget on the environmental factors. As it was pointed out in Haszpra et al. (2005), the carbon exchange of the mixed agricultural region around the tower is mainly governed by precipitation. If the precipitation pattern will change in the future (as it is projected in certain available climate change scenarios, e.g., based on available data from the PRUDENCE project) then it can strongly affect the carbon dynamics of the region.

Fig. 2. shows the annual sums of net ecosystem exchange of carbon (NEE) between the atmosphere and the mixed agricultural vegetation for the 1997-2006 period (year 2000 is missing). Our long term measurement data series suggest that the mixed agricultural landscape generally acts as a net sink of CO_2 from the point of view of the atmosphere (Barcza, 2001; Haszpra et al., 2005). 2003 and 2001 was an exception, when the region released carbon into the atmosphere.

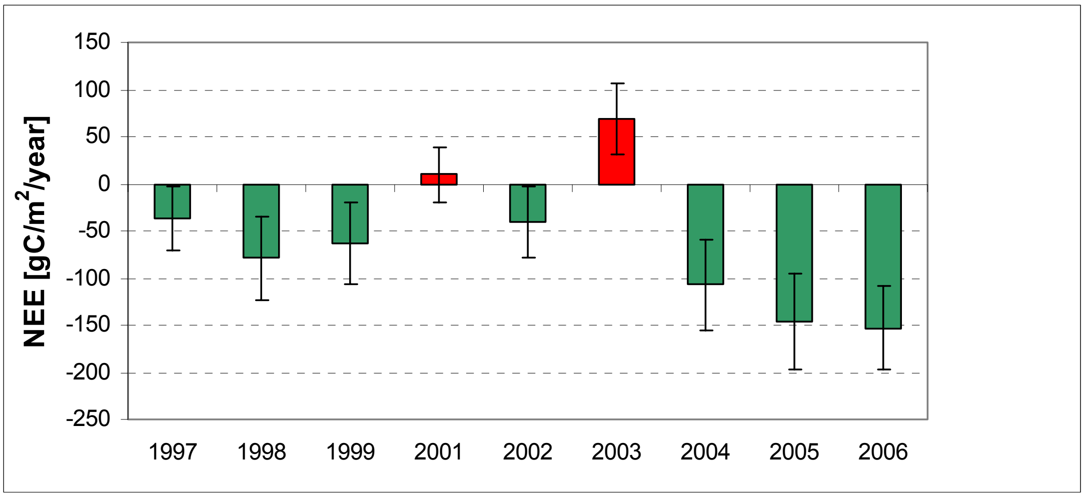

Figure 2. Annual sums of NEE for the 9 years long measurement period (1997–1999, 2001–2006) at Hegyhátsál. Negative values indicate net carbon uptake by the vegetation. Error bars represent measurement uncertainty (Haszpra et al., 2005).

[1] http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_1_2.html

Note that this net carbon uptake or release is only true from the point of view of the atmosphere. The carbon is *not* sequestered in the vegetation but harvested, and part of the biomass (i.e., the yield) is taken away from the fields, then later consumed, and most probably released back into the atmosphere somewhere else. If we take into account this horizontal carbon transport, the agricultural region most probably turns into a net source of carbon to the atmosphere. Unfortunately, we don't have enough information to estimate the amount of carbon that is lost into the atmosphere in this way. Nevertheless, in the context of our present study we only scrutinize the carbon exchange between the atmosphere and the biosphere without taking into account the effect of human or animal consumption.

Climate fluctuations (and probably climate change) affect the net carbon exchange between the atmosphere and the biosphere. For instance, the 2003 heatwave that was coupled with severe drought in large parts of Europe (Ciais et al., 2006), turned the Hegyhátsál region into a significant net source of CO_2 (Fig. 2.). In order to explain what caused the 2003 extreme event it was necessary to separate NEE into gross carbon uptake (caused by photosynthesis) and carbon release (caused by respiration of the living plant and microbial decomposition in the soil). Based on the published methodology (Haszpra et al., 2005), we calculated gross primary production (GPP, gross carbon uptake) and total ecosystem respiration (Reco, gross carbon release) for the mixed agricultural land (NEE is the signed sum of the GPP and Reco). In 2003, both GPP and Reco decreased due to the drought but GPP decreased more than Reco, and the result was a net source activity of carbon in the Hegyhátsál region in 2003 (Table 1.). These results are in accordance with the overall European picture that is a consequence of the 2003 heatwave (Ciais et al., 2006). The heatwave also affected crop yield in Vas county (and also in whole Europe), e.g., winter wheat yield was very low in 2003.

	mean (2003 excluded)	2003	anomaly
GPP [gC/m^2/év]	1182	829	**353 (-29.9%)**
Reco [gC/m^2/év]	1105	898	**207 (-18.7%)**

Table 1. Mean GPP and Reco for the whole measurement period (exluding 2003), and the 2003 anomaly at Hegyhátsál.

If climate change causes similar events in the future then it will act as a positive feedback to global warming since the released CO_2 will increase the atmospheric CO_2 content, thus strengthening the greenhouse effect. Further model-based impact study analysis is needed in the framework of CECILIA to analyze the possible carbon cycle feedback effect of the modified carbon cycle inside the Hegyhátsál region.

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