Climate Change Impacts on Selected Aspects of the Czech Agricultural Production

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Abstract: The article outlines the relationship between meteorological variables and the parts of an agroecosystem which might be significantly influenced by climate change in the Czech Republic. It describes the most often applied scenarios under which projections of changes in meteorological variables up to the year 2050 and their impacts on winter wheat and spring barley yields can be made. It outlines the probable impacts of drought as the most significant hydrometeorological extreme in field production. Finally, case-studies are presented of predicted changes in occurrence of European Corn Borer (*Ostrinia nubilalis*) and predicted changes location and area of zones suitable for the production of different crops.

Keywords: climate change; global climate models; drought; pest; decrease; crop yield

The growing of field crops, for both food and energy, is one of the human activities most influenced by climate. The progress of meteorological elements and the course of processes related to them in every year are unique and non-recurring. Year-on-year differences e.g. in the length of growing season, in the number of days with snow cover, rainfall totals, rainfall distribution, or the temperature itself generate a variability which is quite natural and easily explicable. Growers can flexibly correct for moderate deviations from the average weather by timely cultural practices. But when there is clear evidence of longer-term trends in weather variability, it is necessary to investigate their causes and likely impacts.

There is a broad consensus about the physical cause of climate change among experts from the fields of climatology and meteorology. Published in Paris in 2007, the fourth report of the scientists associated in IPCC organisation (Solomon *et al.* 2007) considers its causes to be anthropogenic activity, above all the release of so-called greenhouse gases which have the ability to absorb long wave radiation. This causes changes in the steady long-term balance between the incoming short-wave radiation from the sun and long wave radiation re-emitted from the earth and its atmosphere. The effect is to accumulate heat in the lower atmospheric layers which alters the phenomena and processes in which heat is consumed and distributed (evaporation, turbulence, convection) and consequently there are a number of climatic impacts. The primary impact is the increase of average temperature (Figure 1). This is directly tied to other meteorological variables – e.g. it influences changes in humidity and atmospheric pressure, formation of cloud, movement of air masses – so the whole climatic system is ultimately affected.

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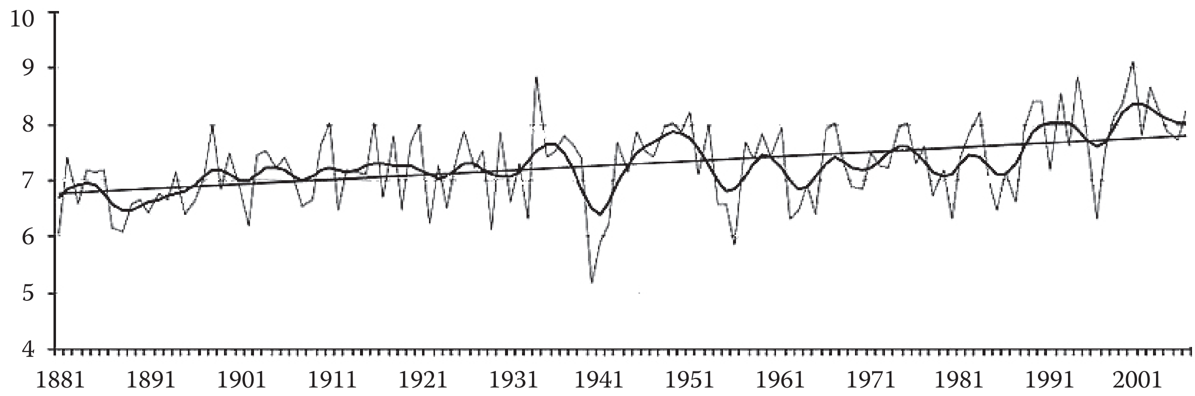

Figure 1. Change of the average yearly temperature (°C), trend curves (Brázdil & Kirchner 2007) in the territory of the Czech Republic (1881–2006)

Although there are also alternative explanations put forward to explain recent global warming, based most frequently on studies of variable sun activity, the available evidence points to the anthropogenic causes (Le Treut *et al.* 2007).

Most scientific studies of the future state of climate are based atmospheric models which require assumptions about greenhouse gases emissions. Scenarios of greenhouse gas concentrations can be constructed and serve as the inputs into so-called Global Circulation Models (GCM), which can be understood as very large sets of mathematical equations describing complex processes in the atmosphere. The values of meteorological variables for different time periods are the outputs. On a regular basis, the years 2025, 2050, 2075 and 2100 are worked with. The most widely used GCMs agree best in their estimates of increase in temperature, whose yearly average is predicted to go up by the year 2100 by about +1.0 to +6.4°C depending on location (in the Czech Republic 1.5–4.5°C). Spatially, the GCM outputs are published in the form of squares (grids) which are used for work in territories of specific interest (state, region, locality). Topical deviations based on the relief of the landscape are taken into account by spatially more precise regional climatic models or various statistical approaches. The biggest differences among predictions of changed temperature are caused by applying different emission scenarios of CO_2. For instance, so-called pessimistic scenarios leads to a large increase of carbon dioxide concentration while so-called optimistic scenarios only lead to a moderate increase in carbon dioxide and so a substantially lower rise of air temperature.

Climate change and field crops

(a) The influence of carbon dioxide

While the problem of estimating climate change under different emission scenarios based on atmospheric and oceanic physics and chemistry is not yet fully understood, modelling the impacts of the changes on the growth and development of crops adds another layer of complexity. The plant physiological processes as well as changes in the soil environment and feedbacks mechanisms must be taken into account together with changes in the crop management practices and various adaptation measures. The very fact that the principle cause of climate change is increased CO_2 concentration has a fundamental effect on the life of plants. CO_2 is the gas used in photosynthesis and its concentration in the current atmosphere (380 ppm) is not optimal for plants. The increase of its content in the bottom layer of the atmosphere will significantly increase the production of biomass of C_3 plants (e.g. wheat, barley) if other conditions remain the same, while the positive reaction of C_4 cycle plants (e.g. corn) will be a lot weaker. Experiments evaluating the growth and amount of biomass definitely prove the stimulating effect on biomass and so, usually, on the yield whether performed in greenhouses or in the open field with direct enriching by carbon dioxide. Regardless of this, the fact that at higher concentrations of CO_2 allows for higher stomata resistance limits transpiration. This increases WUE (water use efficiency) and positively affects production under water limited conditions. There are quite relevant research challenges concentrated e.g. on the questions. (*i*) Is this process time constant? (*ii*) How will the volume of transpired water increase if a crop has greater biomass? (*iii*) How much will higher temperature of leaf surface change the transpiration needed for cooling plants, or simply reduce photosynthesis?

(b) The influence of increased temperature and of the change of rainfall distribution

Temperature is a decisive (but not only) factor which determines the phenological development of plants. The reaching of the individual phases is often determined by a function of temperature expressed by means of the so-called "temperature sum" or "sum of efficient temperatures", which is a cumulative summation of average daily temperature over a defined threshold. Achieving maturity or the beginning of the harvest is almost always earlier in warmer years. If the climate warms, temperature sums will be achieved more quickly and development will be accelerated. This fact is damaging for many of our crops because accelerated development causes yield reduction. Moreover, temperature increase will induce higher evapotranspiration and warmer air will absorb more water vapour; both will lead to a quicker loss of soil moisture. Climate change projections for the territory of the Czech Republic all suggest increased temperatures, especially in summer (Figure 2). Most of GCMs prognosticate an almost unchanged yearly rainfall total for the territory of the Czech Republic (Figure 3), but with more rain in winter and less in summer. Besides, in "vegetation summer" (the period when average daily temperature is higher than 15°C), increased temperatures will strengthen anabatic convective streams, leading to a loss of mild "gardening" rain and an increase in torrential rain, with destructive effects on crops and increased soil erosive potential.

Impacts on yields: positive or negative?

There are two practical ways to assess how the positive fertilising effect caused by carbon dioxide and the negative impact of increased temperature and changes in other meteorological elements will on balance affect crop yields.

(1) By performing field experiments in conditions of controlled atmosphere corresponding to the expected climate conditions. This has the advantage of reality and is consistent with the tradition of field experiments in agronomy. However, there are disadvantages – the time taken, problems in applying the results over larger territories and most importantly, expense.

(2) By the use of computer simulations. For this purpose so called growth models are used. Their disadvantage is inevitable simplification of the simulated system. However, inaccuracies can be kept low enough to allow useful results, providing there is a sufficient body of experimental data allowing for proper calibration and evaluation of the model under range of climate, soil and management conditions.

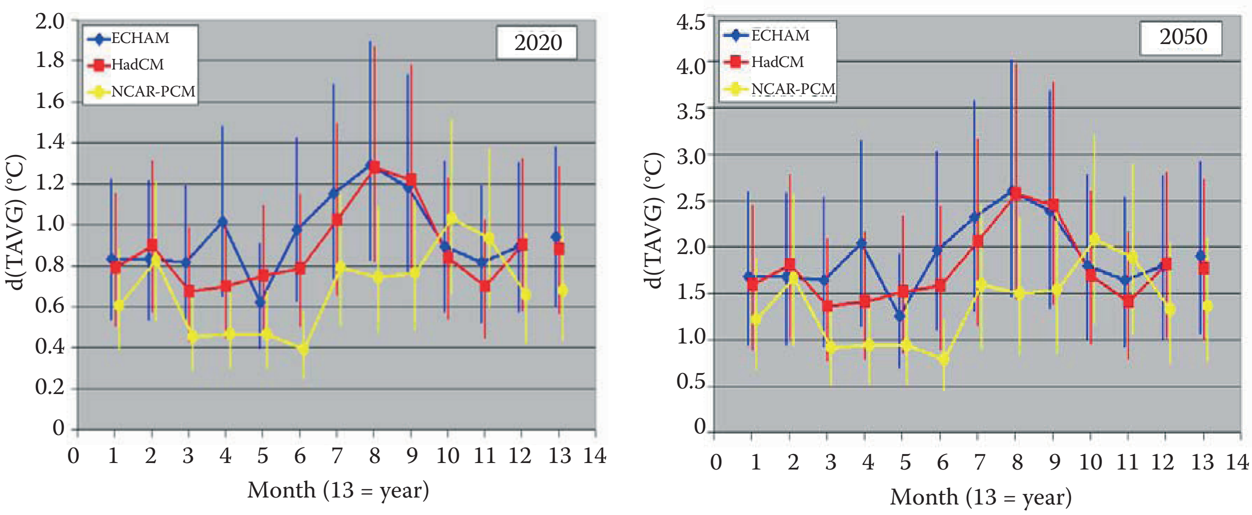

Figure 2. The scenarios of the change of the average monthly and yearly air temperature for the years 2020 and 2050 for the Czech Republic according to ECHAM, HadCM and NCAR models. The curves demonstrate the mean estimate, vertical lines determine the range of values corresponding to SRES – B1 emission scenario, low – low sensitivity (bottom level) and SRES – A2, high – high sensitivity of the climatic model (top level)

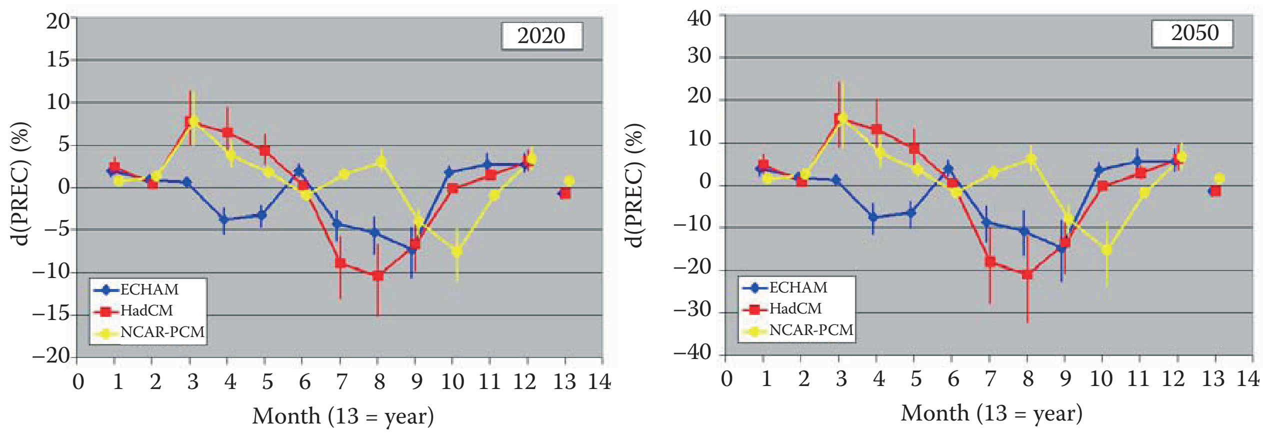

Figure 3. The scenarios of the change of the average monthly and yearly rainfall totals for the years 2020 and 2050 for the Czech Republic according to ECHAM, HadCM and NCAR models. The curves demonstrate the mean estimate, vertical lines determine the range of values corresponding to SRES – B1 emission scenario, low – low sensitivity (bottom level) and SRES – A2, high – high sensitivity of the climatic model (top level)

Probably the best way is to combine both procedures to gain the advantages of both. On the basis of the existence of high-quality small-plot variety experiments performed e.g. by ÚKZÚZ it is possible to carry out detailed tests and calibrations of the growth models in use, which enables to select models whose behaviour corresponds in as reliable a way as possible to the behaviour of the modelled system in the present climate. By replacing meteorological data with GCM outputs representing the expected climate crop development under future scenarios can be estimated. Moreover, trends in measurements of interest e.g. yield, as climate changes can be obtained.

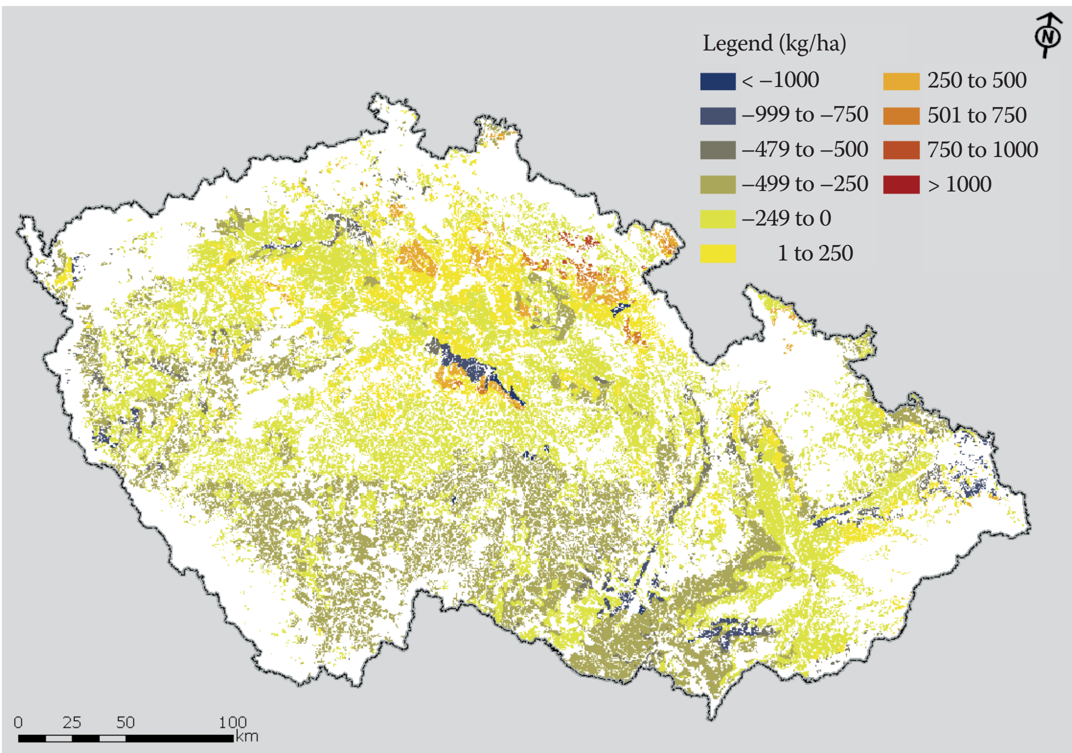

Figure 4. The difference between the yields of spring barley in kilograms per hectare for the present and expected (HadCM3 scenario and CO_2 concentration 535 ppm = A2 pessimistic scenario) climatic conditions, including the CO_2 influence, for the year 2050. The study is calculated for arable land only

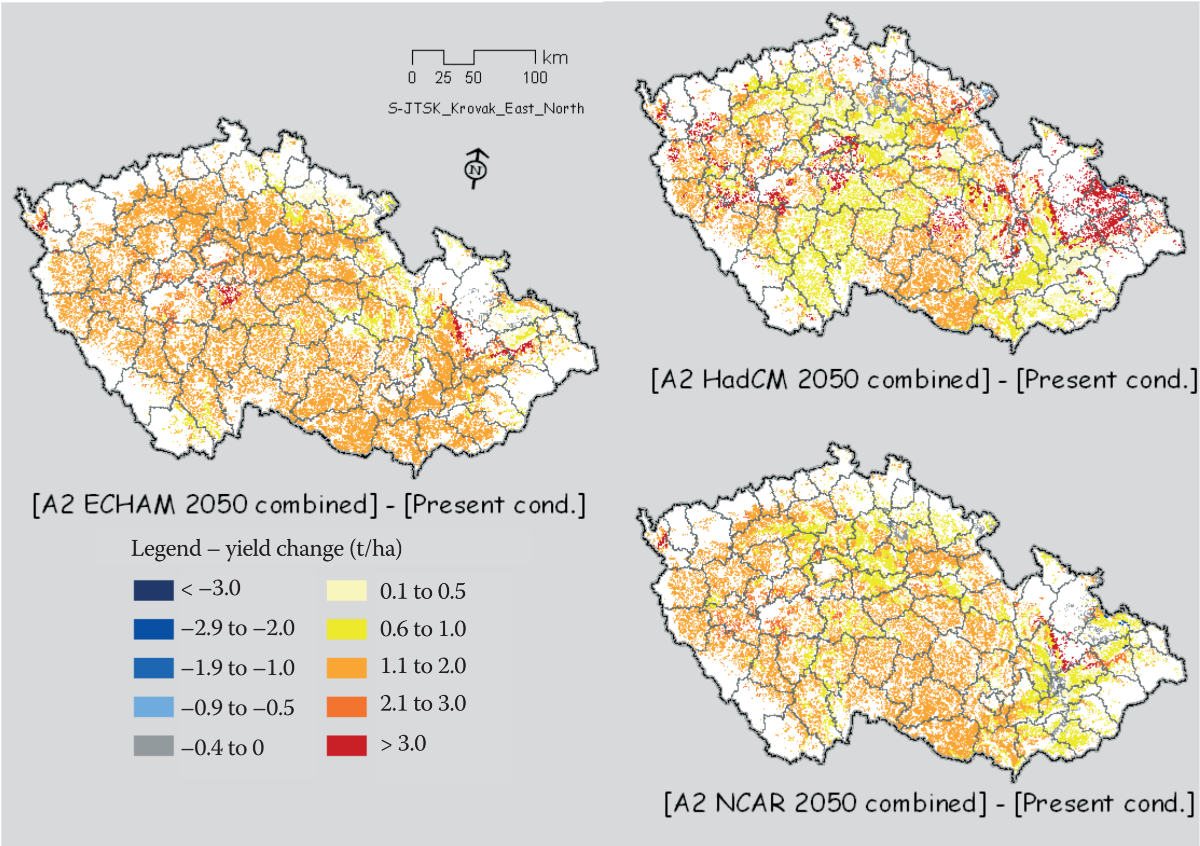

Figure 5. The difference between the yields of winter wheat in tons per hectare for the present and expected (three climate change scenarios and CO_2 concentration 535 ppm = A2 pessimistic scenario) climatic conditions, including the CO_2 influence, for the year 2050. The study is elaborated for arable land only

An example of the climate change impact on the most significant cereal crops

The existing results from a number of European and Czech projects indicate that in the conditions of the Czech Republic, slightly positive effects, mainly on C3 crops, should prevail generally up to a temperature increase of ca 2°C. The Institute of Agrosystems and Bioclimatology, Mendel University of Agriculture and Forestry in Brno, is engaged in model studies concentrating on the assessment of climate change impact on winter wheat and spring barley. Figure 4 offers a view of the change in spring barley yields for all the arable land in the Czech Republic. This particular example shows a situation with rapid temperature increase which would reduce spring barley yields, mainly in lower and drier localities. It applies to the specified conditions only (year 2050, high emission scenario showing a temperature increase of ca 3.5°C) and cannot be taken as prediction but only as one possible scenario of development.

On Figure 5 there are the results of winter wheat which by contrast would have increased yields. The reasons for the contrary reaction are probably wheat's longer growing season and stronger root system at the time of spring drought.

Significant hazards to the agro-ecosystem

(a) Hydrometeorological extremes

More frequent occurrence of hydrometeorological extremes is the greatest hazard connected with climate change. With exceptions, these extremes are difficult to localise in time and space, generally complicated to predict, but at the same time have fierce impacts. Every grower knows the effects of a ten-minute storm accompanied by extreme rainfall at the end of a growing season with otherwise excellent yield progress. Other extreme situations have similar, although not such immediate, impacts – short periods of very warm weather in winter, black frost (low temperature with no snow

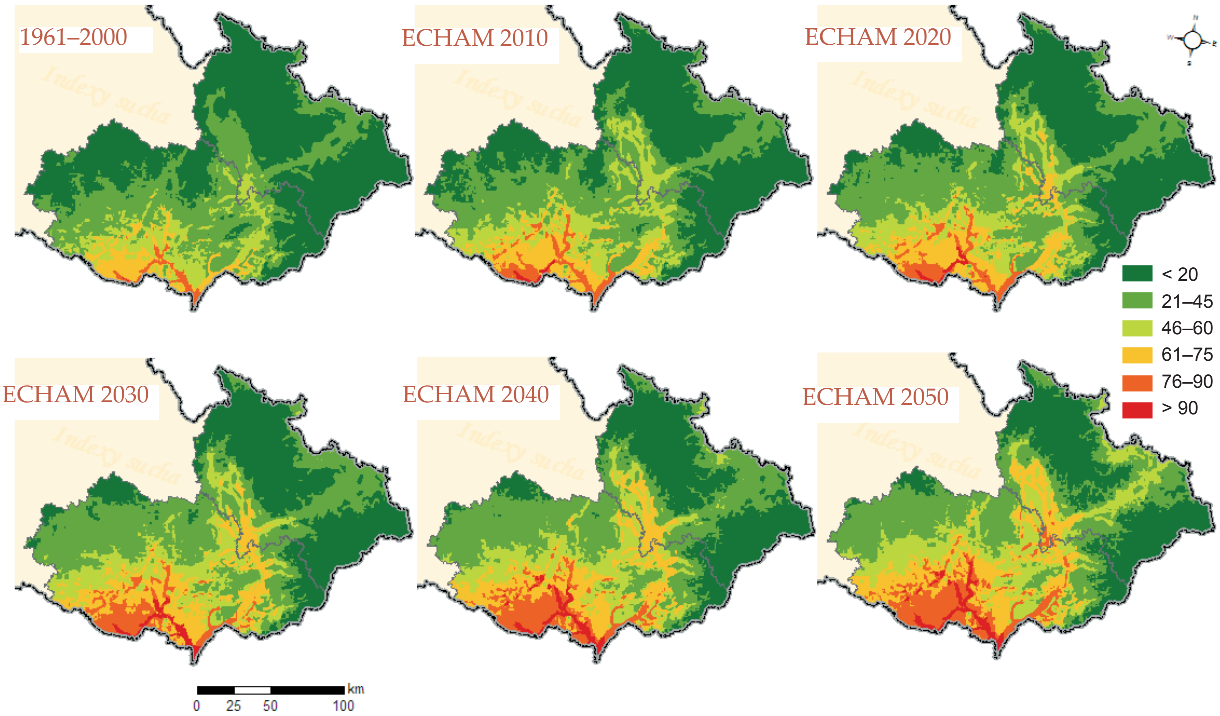

Figure 6. Percentage of months stricken by a period of drought at present (1961–2000) and in expected climatic conditions (2010–2050) based on relative Z-index. Climate change scenario uses ECHAM 4 GCM model outputs. Greenhouse gases concentration was estimated as the average of concentrations expected by SRES-A1 and SRES-B1 scenarios and results with mean sensitivity of climatic system to the changes in greenhouse gases concentration were used. Relative index uses data series 1961–2000 from 96 stations in the territory of Moravia and Silesia as the reference climate. Areas with drought occurrence < 20% can be identified as zero to low risk areas, > 60% high risk areas and > 90% areas with extremely high risk of dry periods occurrence

cover), spring frost, windstorm, flood, heat wave and, above all, drought. The example of drought development for the territory of Moravia and Silesia based on the ECHAM model is the subject of Fig. 6 which uses Palmer's Z-index calculated from water balance of the studied territory. The data used comprise rainfall totals in the tracking period (1 month typically), current water content in soil and evapotranspiration calculated by Thornthwaite's method (Thornthwaite 1948; Palmer 1965).

(b) Occurrence of harmful agents

Another unknown element is the change in infection pressure from diseases, favourability of the climate for pests, and to a certain extent competitive pressures from weeds. The fact that most pathogens, pests and weeds have faster life cycles than crops, trees and large animals also enables them to cope rapidly with changes of the environment. During the last fifteen years some new harmful agents have appeared and others have notably receded (e.g. Olfert & Weiss 2006). These facts might, but need not be, correlated with climate change but it is clear that life cycles of harmful agents with higher dependence on temperature will be influenced more significantly. An example is one of the studies realised at the Institute of Agrosystems and Bioclimatology, Mendel University of Agriculture and Forestry in Brno, by the single purpose model ECAMON (Trnka *et al*. 2007) on the subject of the expansion of European corn borer in conditions of changing climate (Figure 7). In general, studies focused on climate change impacts on diseases and pests conclude that same harmful agents will expand to higher altitudes and may have more generations (e.g. Kocmánková *et al.* 2008) leading to greater in the other site some, pests and diseases of colder areas will tend to decrease damage.

(c) Change of farming conditions

In the broadest measure of the Czech Republic, farming conditions are grouped into production

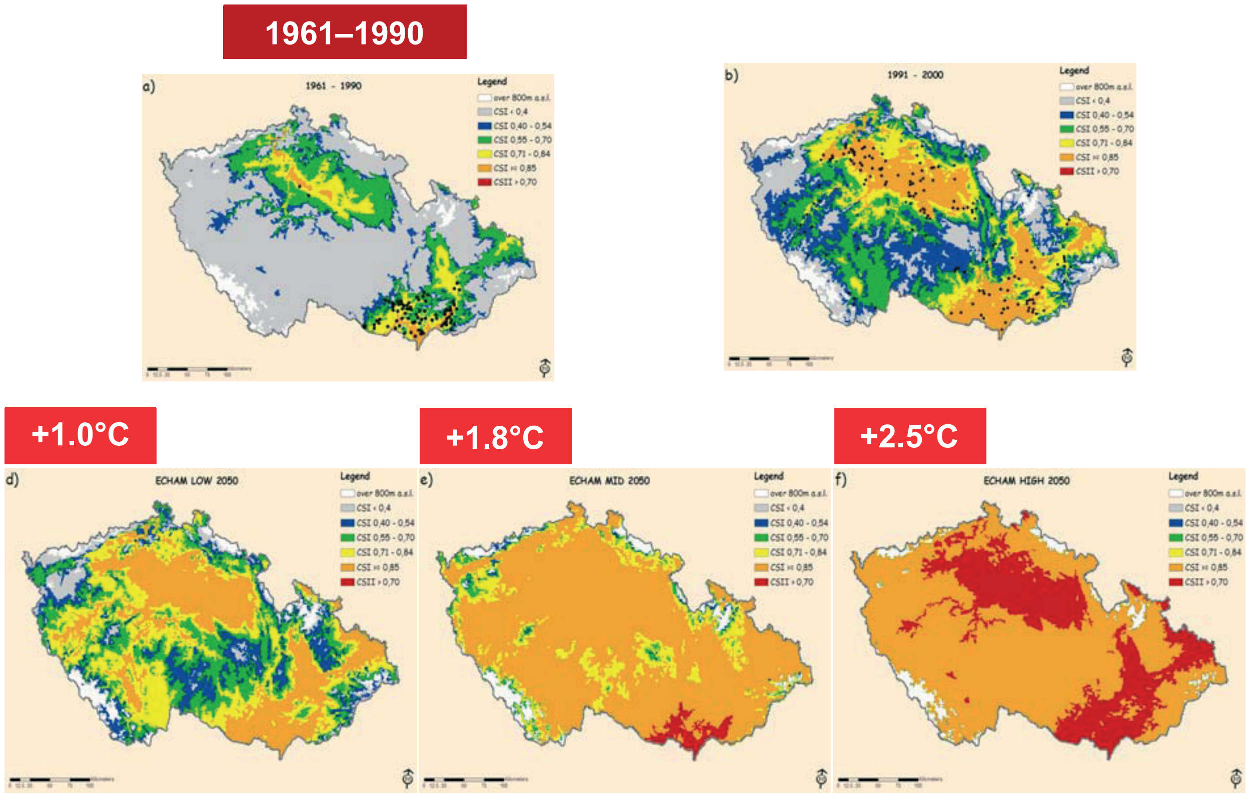

Figure 7. The expansion of ecological niche of European corn borer in the present (at the top) and expected climatic conditions. The black spots show the confirmed appearance of ECB. Dark red signifies localities with possible appearance of the second generation (Trnka *et al.* 2007)

regions (PR). These are defined primarily by climatic conditions although there are other factors, too, as is obvious from the descriptions of the individual production regions (Němec 2001). The presented results are based on the original division of PR adjusted by Němec (1996) but climatic conditions were the only criterion used to project changes both because we do not have access to all the data sources originally used for defining PR and because it would be very difficult to apply the original defining methodology fully in changed climatic conditions. This required changes in the definitions of PR. The temperature sum TS 10°C as defined in the original work by Klečka and Korbíni (1973) was used with two differences (1) the presence of snow cover was taken into account in its calculation using snow cover model SnowMAUS (Trnka *et al.* 2009) and (2) the median instead of the mean of the individual years during the given period was used. The irrigation indicator parameter in the June to August period, given by the difference between the potential evapotranspiration and rainfall (Kvi–viii), was based on a model of water balance using daily time-steps not monthly (Kurpelová *et al.* 1975) as in Klečka and Korbíni (1973) . The main problem of PR definitions is the fact that they are founded on the climatological data from the Czech Hydrometeorological Institute (ČHMÚ) for the years 1931–1961 and the climate has already changed since then (e.g. Květoň *et al.* 2001).

Simultaneously, grain-growing and potato-growing region were merged into a single category because it is not possible to differentiate these region on the basis of climatic data. The required climatic parameters were then interpolated to digital model of terrain (as in the yield studies and analysis of European corn borer) on a 500 × 500 m grid. Besides the existing PR, two new PR categories were defined because in conditions of climate change, some of the territory falls outside any of the original PR definitions. These regions allow for the increased aridity during summer months, indicated by increasing deficits in water balance and by quite dramatic temperature rises. As is obvious from Table 1, for all scenarios there is a dramatic decrease of the acreage of fodder-growing PR. This is caused by the worsening wa-

Table 1. The distribution of the various agro-climatic production areas in the agricultural land of the Czech Republic. The values are given for 3 GCM models (HadCM, ECHAM and NCAR-PCM) on the basis of two emission scenarios, SRES-A2 and SRES-B1. In case of SRES-A2 high sensitivity of climatic system to the growth of greenhouse gases concentrations was considered while in case of SRES-B1, low sensitivity was considered

PR	Present time		HadCM					ECHAM				NCAR-PCM			
			SRES-B1		SRES-A2			SRES-B1		SRES-A2		SRES-B1		SRES-A2	
	Němec (1996)	1961–2000	2025	2050	2025	2050	2100	2025	2050	2025	2050	2025	2050	2025	2050
EWEDPR	–	0.0	0.0	0.0	0.0	14.2	94.3	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0
EWDPR	–	0.0	0.0	0.1	4.0	12.1	2.7	0.0	0.0	0.5	5.2	0.0	0.0	0.0	1.2
CPR	6.7	5.4	20.2	28.6	44.9	56.7	2.8	16.2	22.2	31.2	48.6	14.1	17.5	19.2	21.9
BPR	24.3	23.2	40.0	45.7	39.2	13.8	0.3	34.9	42.4	47.4	35.9	33.1	41.7	54.1	68.7
G-PPR	59.0	59.7	34.8	22.0	10.4	3.0	0.0	42.7	30.7	18.0	6.2	46.7	35.9	23.6	7.4
FPR	10.0	11.8	4.9	3.5	1.5	0.1	0.0	6.2	4.8	3.0	0.8	6.2	4.8	3.1	0.8

EWEDPR – extremely warm and extremely dry production region; EWDPR – extremely warm and dry production region; CPR – corn-growing production region; BPR – beet-growing production region; G-PPR – grain-potato-growing production region; FPR – fodder-growing production region

ter balance at higher altitudes and by increased temperature sum TS10. Fodder-growing PR is gradually replaced with grain-potato-growing PR and by the year 2050 its complete disappearance can be expected. Similarly, there is a dramatic decrease in the acreage of grain-potato-growing PR in favour of beet-growing and finally maize-growing PR. This trend is again due mainly to the increase in temperature sum TS10. In case of beet-growing PR, there is naturally an opposite trend and its acreage according to all scenarios will at the least double by the year 2050. According to SRES-A2 and HadCM and ECHAM GCM models, after about 2050 gradual decline of beet-growing PR acreage is expected due to the increasing aridity of summer climate. However, the results based on the NCAR-PCM GCM model indicate the possibility of increasing the acreage of this PR after the year 2050 because the rate of increase of aridity is lower in this GCM model. Relatively the greatest expansion is in the acreage of maize-growing PR, which is predicted to multiply 4–10 times in the next 50 years from the present 5.4%. Gradually, the maize-growing PR replaces the current beet-growing PR and the warmest parts of the wheat-potato-growing PR. According to SRES-A2, the emergence of the newly defined production regions (i.e. extremely warm and dry PR, extremely warm and extremely dry PR) can be expected as soon as 2025 in the warmest and driest parts of southern Moravia. About the year 2050 extremely warm and dry PR emerges in the surroundings of Prague and in Žatec and Louny regions while in southern Moravia, extremely warm and extremely dry PR covers approximately the extent of the current maize-growing PR. According to the combination of SRES-A2 scenario and HadCM GCM model, almost the whole territory of southern Moravia will fall to the last-mentioned PR by 2100. The progress of PR changes under the emission scenario SRES-B1 is considerably slower but there are still great changes compared to the present conditions. Under HadCM model, SRES-A2 scenario, extremely warm and dry PR appears, mostly in southern Moravia, rarely in Louny, only as late as 2050.

CONCLUSION

The frequent question as to whether climate change can influence the crops grown has in the conditions of the Czech Republic a more or less negative answer. In real terms it is unlikely that the climate will allow massive introduction of new crops or even subtropical crops in the next several decades. The crops grown will be from the practical point of view be influenced much more by the agricultural support policy of the European Union and by the world agricultural markets. Certain changes in conditions of the Czech Republic can be expected rather in the advance of cropping to higher altitudes where soil conditions are considerably worse than in the lowlands. Breeding for resistance to drought will become an adaptation measure, in view of the increasing aridity of both lower and middle altitude territories. The period of time between sowing and maturity in many crops will be shortened, which is likely to reduce yield. The average seeding time e.g. for spring barley will move by 5–20 days to the beginning of the year depending on the season and soil type. The combined impact of climate change, up to the level of +2°C, and the increased CO_2 concentration will bring a moderate increase of yield mainly on high-quality soils but at the same time substantially higher variability of yield connected with drought and other climatic extremes. Higher costs should be expected on plant protection against thermophilous diseases and pests.

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