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EFFECT OF CLIMATE CHANGE AND CLIMATE VARIABILITY ON CROP YIELDS

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1. INTRODUCTION

It is assumed that the climate will change in the forthcoming decades. The question stands what effect the climate change will have on crop production. This contribution gives some results obtained in recent studies made by the authors. These studies were focused on assessing the impacts of the climate change on three crops (maize, winter wheat and spring barley) using the crop growth models and weather generator. Preliminary results were already presented in the last ECAC conference (Dubrovsky *et al.*, 1998). Detailed analysis of impacts on maize is addressed in Dubrovsky *et al.* (2000) and Zalud and Dubrovsky (submitted), analysis of impacts on barley is given in Zalud *et al.* (2000).

2. METHODS AND DATA

The impacts of climate change related to doubled atmospheric CO_2 as well as the impacts of changes in individual climatic characteristics are assessed by comparing the model yields obtained in 99-year crop model simulations run with synthetic weather series representing present and changed climate conditions. Three ***crop models*** (CERES-Maize, CERES-Wheat, CERES-Barley) included in DSSAT v.3 software package (Hoogenboom *et. al.,* 1994) were validated using observed data from two experimental locations (maize and wheat: Zabcice [49°01′ N, 16°37′ E, 179 m a.s.l.]; barley: Domaninek [49°32′ N, 16°15′ E, 560 m a.s.l.]). The weather series for present climate were synthesised by ***weather generator*** Met&Roll (Dubrovsky, 1997) whose parameters were derived from the observed weather series obtained at the two experimental sites (Zabcice 1961-90, Domaninek 1967-94). To generate weather series representing changed climate conditions, the parameters of the generator were modified according to the ***climate change scenario*** (Fig.1) based on ECHAM3/T42 model (Nemesova *et al*., 1999). The non-meteorological input data (pedological, physiological and cultivation data) for each crop model were based on a single representative (typical) year.

The model simulations were run under two environmental settings: ***stressed yields*** relate to water and nutrients limited conditions, ***potential yields*** relate to water and nutrients non-limited conditions. The ***direct effect*** (through increased fertilisation effect of ambient CO_2) and the ***indirect effect*** (through changed weather) of increased CO_2 on both stressed and potential yields are assessed.

3. RESULTS AND DISCUSSION

The changes of individual climatic characteristics projected by the climate change scenario are loaded by different errors. Moreover, changes in some parameters (e.g., interdiurnal variability of weather characteristics) are not addressed by the scenario. To show the effect of these uncertainties, the detailed sensitivity analysis was made in Dubrovsky *et al*. (2000). The effect of changes in individual climatic characteristics included in the climate change scenario on maize yields was studied in Žalud and Dubrovský (submitted), the same analysis for barley (Zalud et al., 2000) and wheat was made recently. The results are displayed in Fig.2 and show:

maize: (i) direct effect: The stressed yields of maize would increase by 36-41 % in a present climate and by 61-66 % in 2×CO_2 climate due to the direct effect of doubled CO_2. Since the improved water use efficiency (WUE) insignificantly affects the yields in water and nitrogen unlimited conditions, the direct effect on potential yields is manifested only by 9-10 % increase. (ii) indirect effect: The stressed yields would decrease by 27-29 % at present ambient CO_2 concentration (by 14-16 % in 2×CO_2 atmosphere) due to the indirect effect of doubled CO_2. The results of the sensitivity analysis suggest that the negative contributions to the change in the stressed yields come from changes in all individual weather characteristics. The increased temperature shortens the phenological phases and does not allow for the optimal development of the crop. The simultaneous decrease of precipitation and the increases of temperature and solar radiation sums reduce the yields through deepening the water stress. In 2×CO_2 atmosphere, the improved WUE reduces the water stress and the decrease of the yields is mainly due to the shortening of the phenological phases. The slight negative indirect effect on the potential yields results as a superposition of large negative effect of increased temperatures and large positive effect of increased solar radiation. As for the standalone effect of solar radiationn, the potential yields increase by the same factor as the solar radiation sums increase. (iii) combined effect: If both direct and indirect effects are considered, the stressed yields should increase in 2×CO_2 conditions by 17-18 %, and the potential yields by 5-14 %.

wheat and barley: (i) The projected climate change will have no apparent effect on stressed wheat yields. On the contrary, the stressed yields of the barley will decrease more significantly than the maize yields. This decrease appears to be due to the temperature changes, the effect of which is more pronounced than the effect on the maize. The effects of changes in solar radiation and precipitation are lower compared to the effects on the maize. (ii) The impacts on potential yields of wheat and barley are similar as on the maize.

The yields obtained at given environmental conditions (weather, ambient CO_2) may be affected by various management responses, such as adjustments in fertilisation and irrigation regimes, shifting the planting date, or using other cultivar. Only the effect of the shift of the planting date (PD) on maize yields is considered here. The 99-year crop model simulations were run for two CO_2 levels and two climates (present climate and 2×CO_2 climate), at water and nitrogen limited conditions. The value of PD was varied within interval $<D_0 - 60$ days, $D_0 + 30$ days$>$, where D_0 = 126 (May 6) is the planting date of the "representative year". The results displayed in Fig.3 show: (i) The model grain yields simulated in present climate conditions (1×CO_2 weather) are rather insensitive to small changes in PD. In case of the earlier PD, the probability that the yield is damaged by a spring frost increases. On the other hand, if the planting date is delayed beyond D_0, the grain yields tend to decrease due to the occurrence of the autumn frosts, which precociously terminate the grain filling phase.. (ii) The 27% decrease of the stressed yields resulting from the changes in daily weather conditions in 2×CO_2 climate, especially from the increased temperature, might be reduced to 17 % by applying earlier planting terms (approx. 1 month sooner compared to D_0), which would allow to prolong the growing period and thereby increase the yields.

4. CONCLUSIONS

The contribution presents selected results obtained in recent studies made by the authors. It is concluded that the impact of changes in individual climatic characteristics on maize yields is generally in good agreement with other authors: The negative effect of increased variability in daily weather series is in agreement with previous studies by Mearns *et al.* (1996, 1997) and Riha *et al.* (1996). The sensitivity of the maize yields to increased temperature and decreased precipitation corresponds to trends found by Maytín *et al.* (1995) and Brown and Rosenberg (1997). The decrease of the stressed maize yields with increased solar radiation sums is reported also by Wolf and van Diepen (1995).

The aims presently followed in our impact studies are: (i) Development of new climate change scenarios (based on GCMs available from the IPCC-DDC database). (ii) Implementation of the new version of the weather generator (which allows to better reproduce statistical structure of daily weather series). (iii) More detailed analysis of impacts on wheat and barley.

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Table 1. Scenarios used in the sensitivity analysis.

scenario		explanation
O	present	parameters of the generator are derived from observed series
A	2×CO2	parameters of the generator are modified according to the climate change scenario (Fig. 3)
C	PREC=const	same as “2×CO2” scenario but the precipitation is unmodified
D	only PREC	only precipitation is modified
E	only SRAD	only solar radiation is modified
F	only TEMP	only daily extreme temperatures are modified
G	var=const	as “2×CO2” but the variances of *TMAX*, *TMIN* and *SRAD* are unmodified

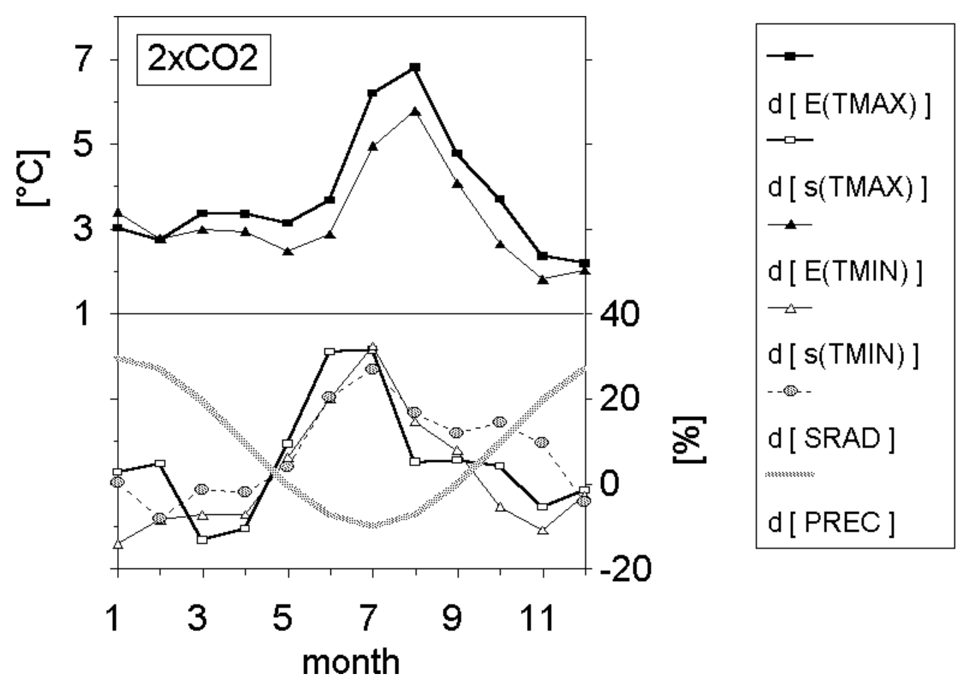

Figure 1. Climate change scenario for 2×CO_2 conditions (adopted from Nemešová *et al.*, 1999). d[E(TMAX)] and d[E(TMIN)] are additive changes of monthly means of daily extreme temperatures, d[s(TMAX)] and d[s(TMIN)] are percentage increments to the standard deviations of *TMAX* and *TMIN*, d[SRAD] are percentage increments to both the means and the standard deviations of daily sums of global solar radiation, and d[PREC] are percentage increments to the daily precipitation sums.

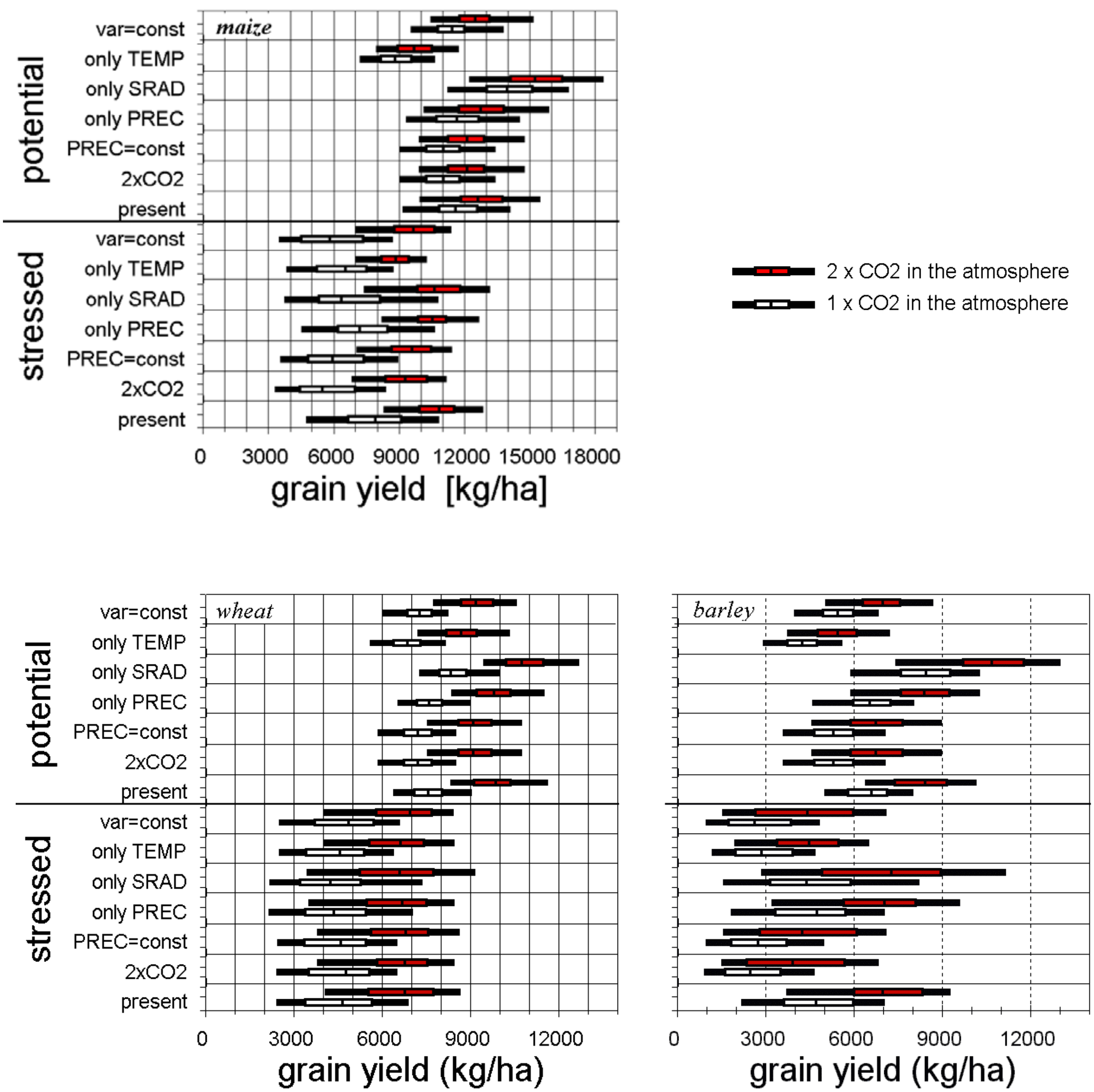

Figure 2. Sensitivity of the grain yields of maize (top), winter wheat (bottom left) and spring barley (bottom right) to changes in individual climate characteristics. The bars represent quantiles (5th, 25th, median, 75th, 95th) of the model yields obtained in the 99-year crop growth simulations run with synthetic weather series. The empty and the red bars relate to present and doubled ambient CO_2 levels, respectively. See Table 1 for the list of the climate sensitivity scenarios.

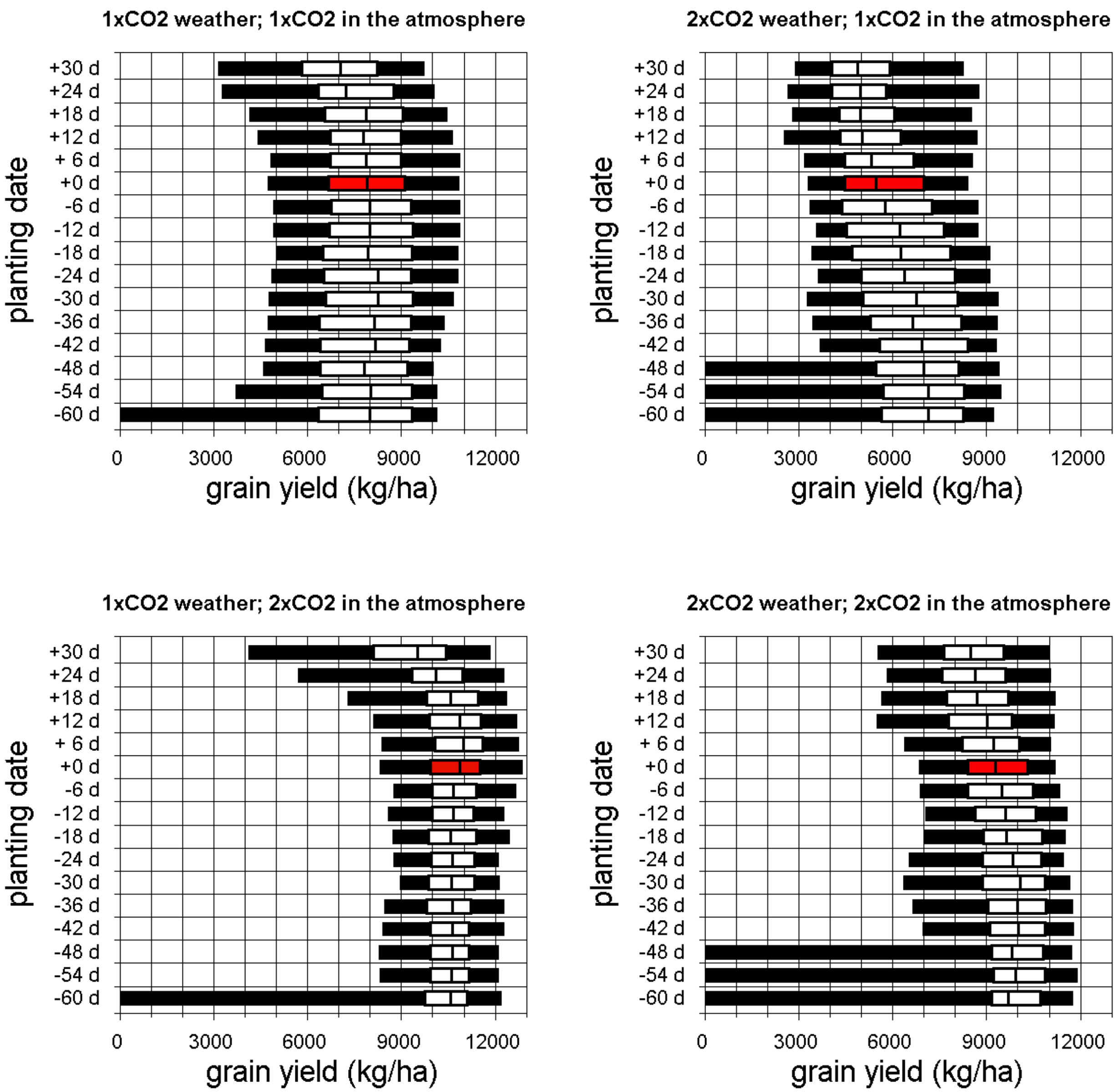

Figure 3. Sensitivity of the grain maize yields to the planting date, which is given in terms of the deviation from the representative year's planting date (May 6 = the 126th day of the year). The bars represent quantiles (5th, 25th, median, 75th, 95th) of the model yields obtained in the 99-year crop growth simulations run with synthetic weather series at two levels of ambient CO_2 (1×CO_2 and 2×CO_2 in the atmosphere) and two weather regimes (1×CO_2 and 2×CO_2 weather). The planting date marked as "+0d" relates to the representative year's planting date.