

MODELLING CLIMATE CHANGE IMPACTS ON MAIZE YIELDS IN THE CZECH REPUBLIC

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Abstract. Crop growth model CERES-Maize was used to simulate maize yields in present and changed climate conditions. The input daily weather series (precipitation, solar radiation and extreme temperatures) were synthesised by stochastic weather generator Met&Roll whose parameters were derived from observed weather series and then modified in accordance with climate change scenario. The contribution addresses following points: **1)** Validation of CERES-Maize model: The grain yields simulated by CERES-Maize with use of measured site-specific pedological, physiological, cultivation and meteorological data were compared with observed grain yields (section 0). **2)** Validation of weather generator Met&Roll (section 0): The stochastic structure of synthetic vs. observed weather series was compared. **3)** Validation of variability of grain yields simulated by CERES-Maize (section 0): To examine how the weather generator's imperfections affect the model yields, the distributions of grain yields simulated with use of observed vs. synthetic weather series were compared. **4)** Sensitivity of grain yields to selected characteristics of weather series (section 0): To gain a notion on possible errors resulting from inaccuracy of climate change scenarios and from ambiguities in projecting climate change scenario into parameters of weather generator, the sensitivity of model yields to selected characteristics of daily weather series (including variability and persistency of the series) was studied. **5)** Modelling maize yields for 2xCO₂ climate (section 0). The climate change scenario related to doubled CO₂ was based mainly on ECHAM GCM simulations.

INTRODUCTION

To study impacts of climate variations on crop production, the crop growth models are employed (Mearns *et al.*, 1997). These models require series of daily weather characteristics to simulate crop growth in daily steps. The weather series representing current and changed climate conditions may be synthesised by weather generator (WG) whose parameters are derived from observed series and modified in accordance with climate change scenario.

This contribution reviews results of experiments made with weather generator Met&Roll and crop growth model CERES-Maize (Dubrovsky *et al.* (accepted)).

CERES-MAIZE SIMULATIONS

The CERES-Maize model (used, e.g., by Bacsi and Hunkár, 1994; Maytín et al, 1995), version 3.0, included in the DSSAT3 software package was used to simulate the crop growth. The input data (pedological, physiological, cultivation and meteorological data) were taken from Zabcice (South Moravia) experimental site.

MET&ROLL

Met&Roll (Dubrovský, 1997; see www.ufa.anet.cz/wg.htm#MR for details) is a 4-variate (daily sum of global solar radiation *SRAD*, daily precipitation amount *RAIN*, extreme daily temperatures *TMAX* and *TMIN*) WGEN-like weather generator designed for use with crop growth model CERES. Precipitation occurrence is modelled by the first-order Markov chain, precipitation amount by Gamma distribution and radiation and extreme temperatures by trivariate first-order autoregressive (AR) model (Wilks, 1992). The set of parameters of Met&Roll consists of: **(a)** means and standard deviations of *SRAD*, *TMAX* and *TMIN*, defined separately for wet and dry days (annual cycle is expressed in daily steps), **(b)** two parameters of Gamma distribution and two parameters of Markov chain model (annual cycle is expressed in monthly steps), **(c)** two 3x3 matrices of AR model (annual cycle is not considered).

VALIDATION OF CERES-MAIZE

The CERES-Maize model was validated by comparing observed grain yields (Zabcice, 1980-1996) with model-simulated grain yields. The results (Figure 1) show good correspondence between observed and simulated grain yields.

(please note that the crop growth simulations reported in following paragraphs were made with slightly different experimental settings, since the validation of CERES-Maize model was made as the last step of this study because of the problems with gathering the input data for the crop growth simulations)

VALIDATION OF STOCHASTIC STRUCTURE OF SYNTHETIC DAILY WEATHER SERIES

The stochastic structure of synthetic series generated by WG should be the same as the structure of observed series. The validation tests have, however, revealed some discrepancies: **(i)** the frequency of occurrence of long dry spells, extreme values of daily precipitation amount and variability of monthly means are underestimated by MET&ROLL; **(ii)** solar radiation and extreme temperatures do not follow normal distribution assumed by AR model; **(iii)** correlations and lag-1 correlations of weather characteristics have significant annual cycle not assumed by AR model. **(iv)** The model generally performs better in summer months.

VALIDATION OF VARIABILITY OF GRAIN YIELDS SIMULATED BY CERES-MAIZE

The question stands how the imperfections in reproducing the stochastic structure of weather series affect the model yield characteristics. To give an answer, the distributions of grain yields simulated with use of observed vs. synthetic (generated by Met&Roll) weather series for 17 Czech locations were compared. No statistically significant difference was detected and it is thus accepted that the synthetic weather series generated by MET&ROLL are applicable to crop growth simulations (at least in Central European climate conditions).

SENSITIVITY OF GRAIN YIELDS TO SELECTED CHARACTERISTICS OF WEATHER SERIES

The problem arises how to project climate change scenario into parameters of WG. For example, the scenario may prescribe to increase monthly precipitation by 10%. However, it does not specify if the change is due to increasing number of wet days, or increasing mean daily precipitation amount, or both. To gain a notion on possible errors resulting from ambiguities in projecting climate change scenario into parameters of WG, the sensitivity of model grain yields to selected characteristics of the weather series was examined. The set of characteristics considered includes those which are not explicitly treated by typical climate change scenario but they are controllable by WG. Selected results are displayed in Figure 2.

MODELLING GRAIN YIELDS FOR 2XCO₂ CLIMATE

The grain yields for 2xCO₂ conditions were simulated by CERES-Maize. The input data for the crop growth simulations were the same as in experiments reported in sections 0 and 0 except for the weather data. Daily weather series were generated by weather generator with parameters modified according to the climate change scenario displayed in Figure 3 (Kalvova et al., to be published): the changes of daily extreme temperature are based on GCM (ECHAM) simulations; solar radiation changes are estimated from changes of daily extreme temperatures using a regression model, and precipitation changes are based on IPCC recommendations, ECHAM validity experiments and experiences from previous studies. The quantiles of the grain yields from the 99year crop growth simulation experiment are displayed in Figure 4.

CONCLUSIONS

(i) The crop growth model CERES-Maize was found to be successful in simulating grain yields in Zabcice experimental site (Figure 1).

(ii) The weather generator fails to reproduce some features of stochastic structure of daily weather series...

(iii) ... however, the differences between distributions of model grain yields simulated with synthetic and observed daily weather series were found statistically insignificant. This indicates that

the imperfections involved in generator's model need not have a pronounced effect on reliability of yields simulated by the crop growth model.

(iv) The sensitivity analysis (Figure 2) indicates that the characteristics not included in typical climate change scenario may affect the yields. For example, increasing persistence of the series (scenarios D and I) or increasing variability of extreme temperatures and solar radiation (C) decrease model grain yields.

(v) The crop model simulations for the 2xCO₂ climate (Figure 4) suggest lower mean and lower variability of the grain yields.

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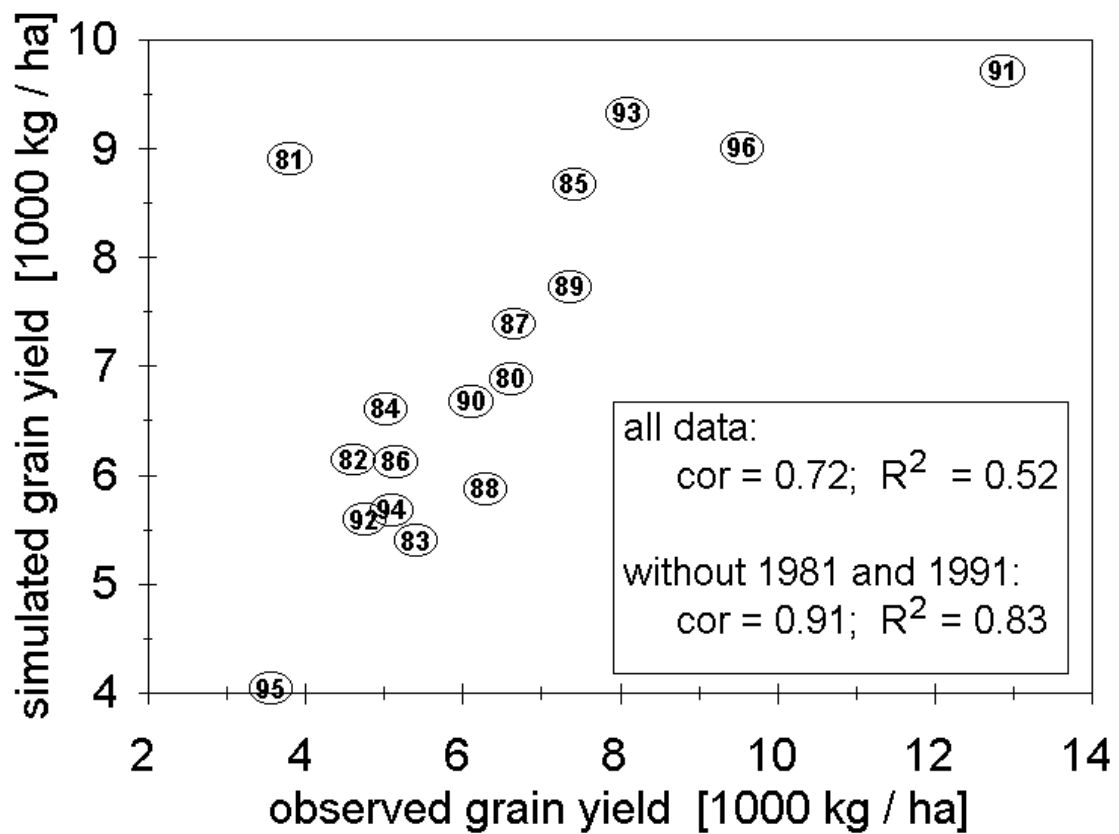


Figure 1 Validation of the CERES-Maize model. The markers (circle with year index) represent grain yields measured in Zabcice (South Moravia) during 1980-1996 (horizontal axis) vs. grain yields simulated by CERES-Maize with authentic site-specific pedological, physiological, cultivation and meteorological data. The correlation coefficient is 0.72 ($R^2=0.52$). In case the two "outliers" (1981 and 1991) are ignored, the correlation coefficient is 0.91 and $R^2=0.83$.

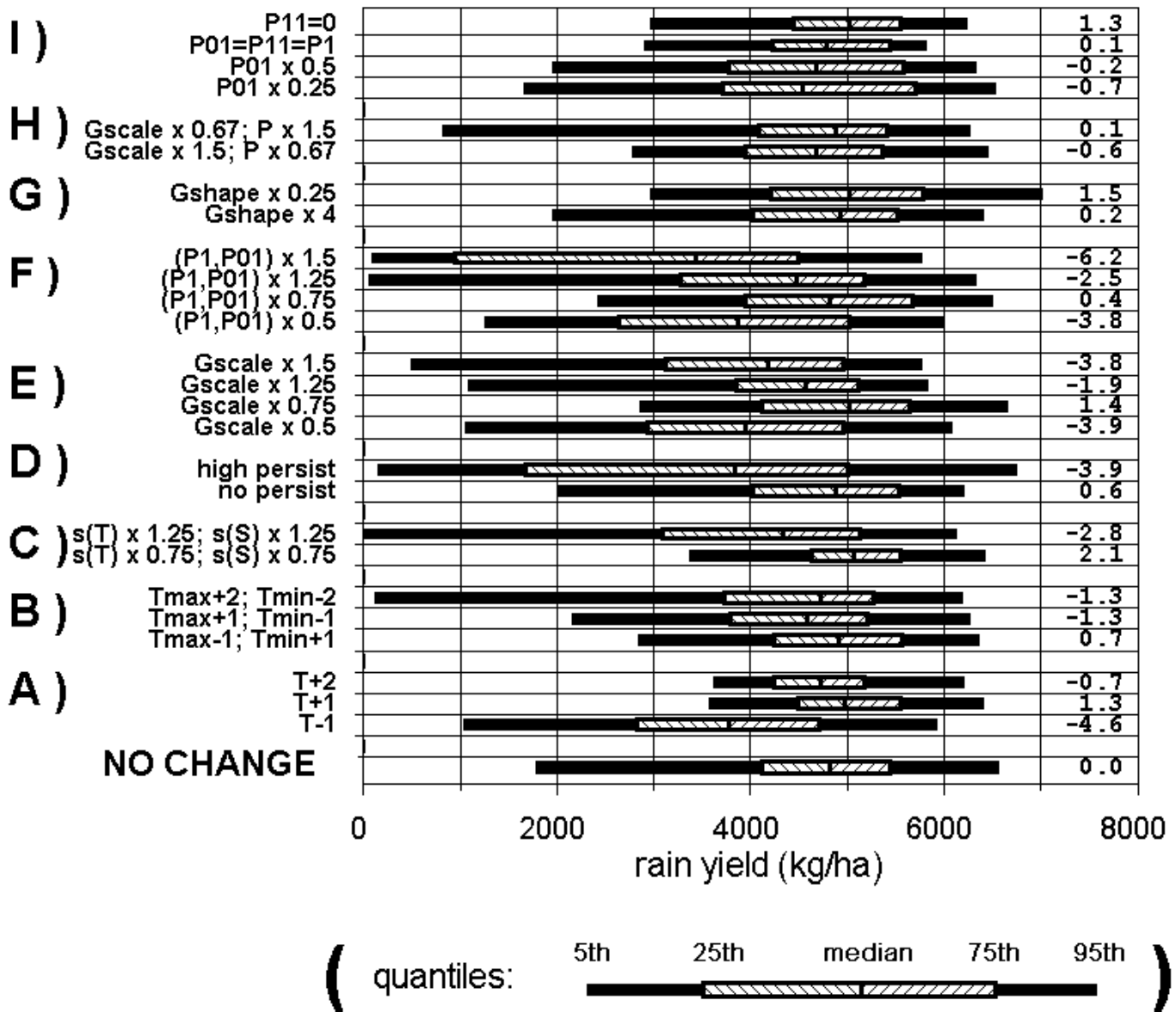


Figure 2. Variability of model grain yields simulated with modified characteristics of daily weather series. The horizontal bars demarcate quantiles of sets of the yields from the 99-year crop growth simulation experiments. The numbers on the right to each bar are values of the standardised Wilcoxon statistic for testing the hypothesis that the distribution of the grain yields does not differ from the reference "no-change" distribution related to unmodified parameters of WG. The values of the statistic beyond $\langle -1.96, 1.96 \rangle$ indicate statistically significant (level of significance = 5%) difference of the two distributions. Scenarios: **A)** temperature means are additively modified by $\Delta T = -1, +1, +2$ ° C, daily temperature amplitudes are preserved (means of TMAX and TMIN are changed by the same increment); **B)** daily temperature amplitudes are changed, daily temperature means are preserved; **C)** standard deviations of TMAX, TMIN and SRAD are multiplicatively modified (the means are preserved); **D)** persistence of daily series of SRAD, TMAX and TMIN is modified ("no persist": lag-1 correlations are set to zero, "high persist": lag-1 correlations are increased to about 90% of lag-0 correlations); **E)** monthly sums of precipitation are changed by multiplying Gamma distribution parameters (mean daily precipitation amounts are changed, percentages of wet days are preserved); **F)** monthly sums of precipitation are changed by modifying probabilities of wet day occurrence (monthly means of temperature and solar radiation are preserved); **G)** shape of Gamma distribution is changed (mean daily precipitation sums are preserved); **H)** daily precipitation sums and percentages of wet days are changed (monthly sums and means of RAIN, TMAX, TMIN and SRAD are preserved); **I)** persistence of the wet day occurrence series is changed by modifying transition probabilities of the Markov chain model.

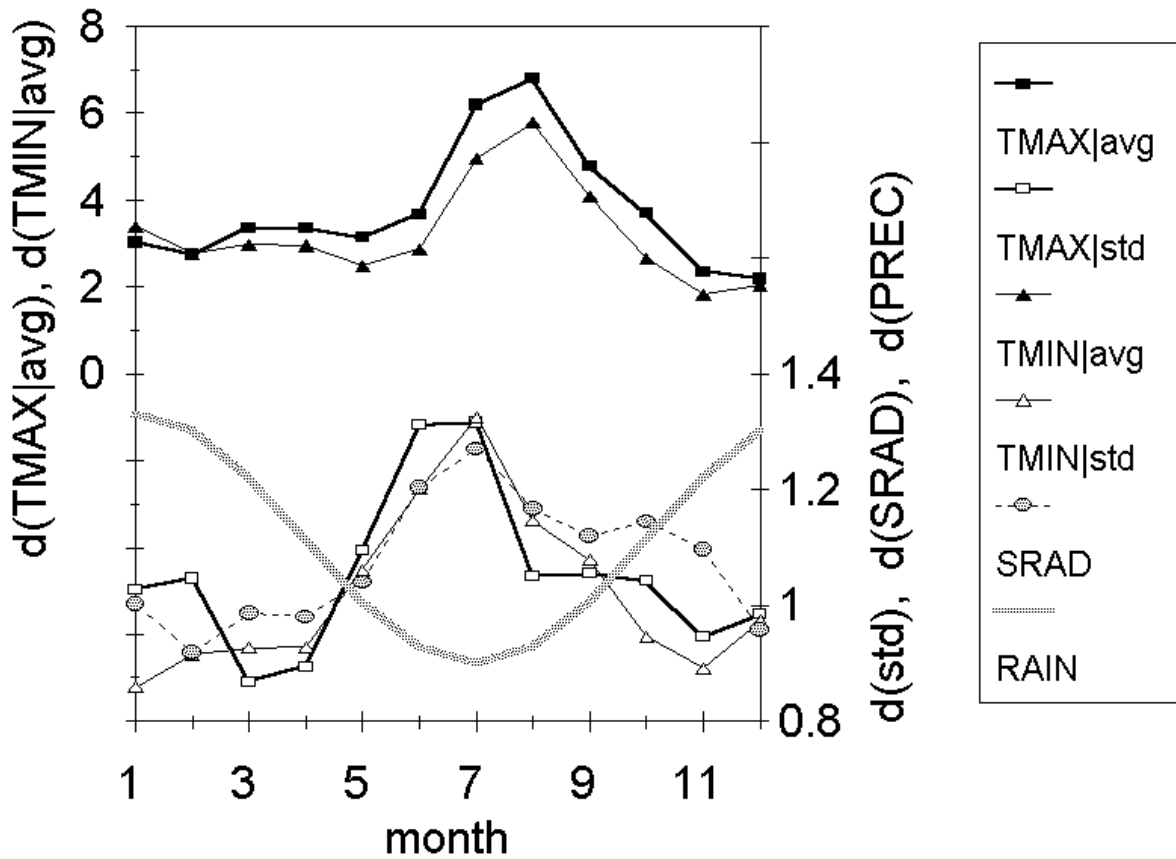


Figure 3. Climate change scenario for 2xCO₂ conditions, South Moravia. The two upper curves represent additive changes of monthly means of daily extreme temperatures. The four lower curves represent multiplicative changes of standard deviations of daily extreme temperatures, solar radiation and precipitation. The changes of daily extreme temperature are based on GCM (ECHAM) simulations; solar radiation changes are estimated from changes of daily extreme temperatures using a regression model and precipitation changes are based on IPCC recommendations, ECHAM validity experiments and experiences from previous studies.

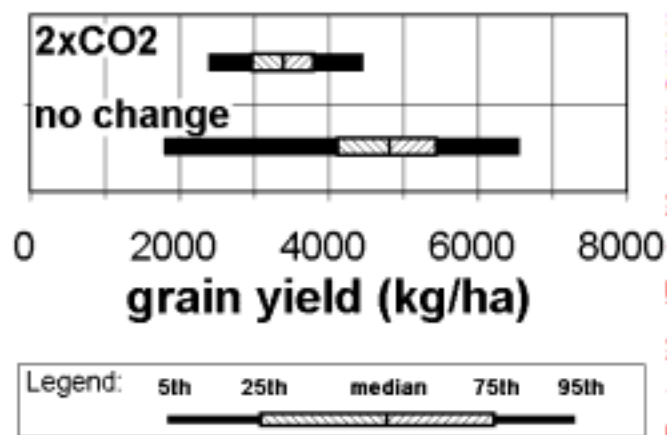


Figure 4. Grain yields simulated by CERES-Maize for 2xCO₂ climate. The horizontal bars demarcate quantiles of sets of the yields from the 99-year crop growth simulation experiments.