IMPACT OF CLIMATE CHANGE ON CROP PRODUCTION POTENTIAL - OBJECTIVES AND METHODOLOGY

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Abstract

Climate change impact on crop growth and development is estimated mostly by two different methods:

1) Experimental methods: the crop is grown under controlled conditions (a glasshouse with controlled atmosphere, open top chambers etc.). An advantage of these methods is the experimental character of the trials and the disadvantage is that these methods have some specific restrictions and are time and money demanding. 2) Simulation methods: due to intensive development of computers and related software the impacts of climatic changes on crop growth can be estimated by highly sophisticated computer models. These methods is rapid and cheap. Nevertheless, the models are still based on experimental results and may carry their restrictions also to the models.

The main objective of this paper is to introduce the methodology for estimation of climate change impact on crop production potential. The main steps towards reaching this goal are as follows:

1. parameterization of crop growth models and validation of crop model yield predictions with respect to regional conditions
2. evaluation of climate change scenario based on GCM and generating synthetic weather data for present and changed climates by a weather generator
3. modelling and assessment of impacts of elevated CO_2 concentration and the related changed climatic conditions on crop yields
4. estimation of the change in crop production potential
5. analysis of sensitivity of model-predicted crop yields to specific meteorological variables
6. adaptation analysis

Introduction

Climate change impacts on crop growth and development have been estimated mostly by two different methods:

1) Experimental methods - the crop is grown under controlled conditions (a glasshouse with controlled atmosphere, open top chambers, etc.). An advantage of these methods is just the experimental character of the trials and the disadvantage is that these methods have still its specific restrictions and are time and money consuming. 2) Use of simulation methods - due to forced development of computers and software the impacts of climatic change on crop growth can be estimated by highly sophisticated computer models. This

method is fast and cheap in application. Nevertheless, the models are still based on results from experiments and may carry its restrictions also to the models.

Material and Methods

The main objective of this paper is introducing of methodology for climate change impact on crop production potential used in Trnka *et al.*, (2000), Šťastná (2000), Žalud (2000), (all contributions in this volume). The main steps reaching the aims are as follows:

7. parameterization of crop growth models and validation of crop model yield prediction for regional conditions,
8. evaluation of climate change scenario based on GCM and generating of synthetic weather data for present and changed climate by a weather generator,
9. modelling and assessment of impacts of elevated CO_2 concentration and related changed climatic conditions on yield,
10. estimation of the change of crop production potential,
11. sensitivity analysis of crop model predicted yields to specific meteorological variables
12. adaptation analysis for sowing date,

using a combination of experimental and simulation procedures.

Results

The results of this study was carried out by several steps:

1) Parameterization of CERES-Maize, CERES-Barley and CERES-Wheat growth models : The grain yields were simulated by the tree crop growth models which are part of DSSAT (Decision Support System for Agrotechnology Transfer) software (Hoogenboom *et al*. 1994) with use of measured site-specific pedological, physiological, cultivation and meteorological data. The results are compared with observed grain yields. Observed data from seventeen years were evaluated for maize, ten years for barley, and nineteen years for wheat.

2) Generating of synthetic data sets by a weather generator for present and changed conditions: Met&Roll is a freely available (http://www.ufa.anet.cz/dub.htm#met&roll) WGEN-like (Richardson 1981) four-variate stochastic weather generator (Dubrovský, 1997). It is designed to provide synthetic daily weather series representing present and changed climate conditions to be used in crop growth modelling (Žalud *et al.,* 1999).

Precipitation (*RAIN*) is modelled by a first-order two-state Markov chain (occurrence) and Gamma distribution (amount). Standard deviations of daily extreme temperatures (*TMAX* and *TMIN*) and daily sums of global solar radiation (*SRAD*) are modelled by a first-order trivariate autoregressive (AR1) model. The ability of Met&Roll to reproduce the statistical structure of observed daily weather series was examined by Dubrovský (1997). Parameters of the WG were derived from observed weather series and then modified in accordance with climate change scenario. The scenario related to doubled atmospheric CO_2 is based on the ECHAM3/T42 GCM model (Nemešová, *et al.,* 1999). This approach allows to perform a detailed sensitivity analysis to changes in the statistical structure of weather series

3) Modelling crop yields for 2×CO_2 climate conditions: A 99-year crop simulation experiment was carried out using synthetic weather series (precipitation - *PREC*, solar radiation - *SRAD* and extreme air temperatures - *TMIN* and *TMAX*) and other input data taken from the created generic year.

4) Estimation of the change of crop production potential: As an indicator of climate change impacts on crop production the relative index of production potential was computed as ratio between average of simulated stressed and potential yield.

5) Sensitivity analysis: The sensitivity analysis was made in order to reveal the role of projected changes of individual weather characteristics and the direct effect of increased CO_2 on potential and stressed yields. The climate change scenario defines changes of the means and variability of four daily weather characteristics used for the crop simulation. (Since individual changes were affected by different errors, the sensitivity analysis was done to estimate the impact of changes in individual weather characteristics). For each sensitivity scenario, a 99-year simulation with synthetic series was carried out for potential and stressed (water and nutrients limited) simulations and 1×CO_2 and 2×CO_2 concentrations in the atmosphere.

The set of scenarios used in the sensitivity analysis include:

- present — parameters of the WG are derived from observed series (1961-1990)
- 2×CO2 scenario — parameters of the WG are modified according to GCM-based
- PREC = const — same as "2×CO2" but the precipitation parameters are unmodified
- only PREC — only precipitation parameters are modified
- only SRAD — only solar radiation parameters are modified
- only TEMP — only temperature parameters are modified
- var = const — as "2×CO2" but variances of *SRAD*, *TMIN* and *TMAX* are unmodified

6) Adaptation analysis: The yields may apparently be modified by various management responses, such as adjustments in fertilisation and irrigation regimes, shifting the planting date, or using other cultivar. Only the shift of the planting date (PD) for maize is considered in this metodology.

The 99-year crop model simulations were run in WG approach 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".

Experiment results based on this methodology are discussed in detail in Trnka *et al.,* (2000), Šťastná (2000), Žalud (2000), (all three contributions in this volume).

Conclusions

The contribution describes the methodology used to evaluate the climate change impacts on crop yield. Long term field experiments create a database for crop growth model calibration and validation. The real meteorological data are replaced with the synthetic series generated by stochastic weather generator. Firstly, the parameters of the generator were derived from the observed series and were used to generate weather series representing the present climate; secondly, parameters of the generator were modified in accordance with the climate change scenario to generate series representing the changed climate. This approach allows to perform detailed analysis of sensitivity to changes in statistical structure of weather series. For each sensitivity scenario, a 99-year simulation with synthetic series was run for potential and stressed (water and nutrients limited) simulations and 1×CO_2 and 2×CO_2 concentrations in the atmosphere. The change in the crop production potential (ratio of stressed and potential yields) should be computed as a objective index of impact of changing weather condition on crop yields.

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Abstrakt

Příspěvek představuje metodiku používanou pro posouzení dopadů změny klimatu na kulturní plodiny. Na základě polních experimentů je provedena kalibrace a evaluace příslušného růstového modelu jehož vstupní meteorologické údaje jsou nahrazeny údaji syntetickými, které jsou vytvořeny pomocí stochastického meteorologického generátoru. Parametry generátoru jsou upraveny podle použitého scénáře změny klimatu. Simulace 99-četných souborů umožňuje statistické zpracování jednotlivých experimentů a výpočet indexu produkčního potenciálu pro reálný i potenciální výnos jako podílu mezi průměrným výnosem v podmínkách 1xCO_2 a 2xCO_2 klimatu. Metodika je doplněna návodem na provedení citlivostní analýzy pro posouzení významu změny jednotlivých meteorologických prvků v produkčním procesu rostlin.

Key words: crop model; stochastic weather generator; climate change; yield

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