MODELOVÁNÍ DOPADU ZVÝŠENÉ KONCENTRACE CO_2 NA VÝNOS PŠENICE OZIMÉ
MODELLING OF INCREASED CO_2 IMPACT ON WINTER WHEAT YIELD

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ABSTRACT

Parameterization and validation of the dynamic crop growth CERES-Wheat model was done by the data obtained in a long-term field experiment (1975–1993) conducted in Kroměříž (49°18´ N, 17° 23´ E, 204 m above the sea level) and (1975-1996) Žabčice (49 °01´ N, 16 ° 37´ E, 179 m). The weather input data were obtained by the stochastic weather generator in order to estimate the climate change impact on the wheat yield. Statistical parameters of the weather generator were based on the outputs of the observed series (the present state) and modified in accordance with the climate change scenarios based on the general circulation model ECHAM3/T42.

The combination of direct and non-direct influences of higher CO_2 concentrations increased the simulated outputs of wheat yield. The potential yield increased by about 17% and the stressed yield by 31% in the 2xCO_2 climate. The indirect impacts of the climate change were slightly negative but the combined impact (direct and indirect influences) gave higher yield compared to the present climate. The potential level showed a similar trend. In comparison with the C4 crops, the reaction of wheat (C3) to rising CO_2 was more intensive with respect to utilization of such an amount of CO_2 in the less perfect biochemical cycle of photosynthetic assimilation. Surprisingly, the available water was not a limiting factor for wheat.

The relative index of production potential, used as an indicator of climate change impact on crop production, was computed as a ratio of average simulated stressed and potential yields. The production potential of wheat (ratio of stressed and potential yields) increased from 59% (1×CO_2 climate) to 64 % (1.5×CO_2 climate) or 69 % (2×CO_2 climate).

INTRODUCTION

Dynamic crop-growth models are used to project the effects of rising atmospheric CO_2 concentration and associated climate change on crop yields. Yield responses to climate and management were already simulated with CERES-Wheat (Ritchie and Otter, 1985; Ritchie et al., 1988; Godwin et al., 1990). A process-based mechanistic model that simulates daily phenological development and growth in response to environmental factors (soil and climate) and management (crop variety, planting conditions, nitrogen fertilization, and irrigation). The model is designed to have applicability in diverse environments and to utilize a minimum data set of commonly available field and weather data as inputs. CERES-Wheat has been calibrated and validated over a wide range of agro-climatic regions (Rosenzweig and Iglesias, 1998, Žalud and Dubrovský, 1999) and modified to include leaf-level photosynthesis response to elevated CO_2 using field data from 2 years of Free-Air Carbon Dioxide Enrichment (FACE) experiments with spring wheat (Triticum aestivum L. cultivar Yecora Rojo) in Maricopa, AZ. Simulations of DM (dry matter) and grain yield were within 10% of measured values, except for a tendency to overcalculate DM response to CO_2 by 10 to 15% in Year 1 for WS (water-deficit stressed) treatment (Francesco, 1999). The analysis of winter wheat production process in conditions of possible climate change for Czech Republic was done by the CERES-Wheat model in Žalud, Dubrovský (1999).

MATERIAL AND METHODS

The main objective of this paper is to find out the climate change impact on wheat production potential. The main steps reaching the aim are as follows:

1. parameterization of CERES-Wheat growth model and validation of the wheat model yield prediction for regional conditions
2. evaluation of climate change scenario based on GCM and generating of synthetic weather data for present and changed climate by a weather generator
3. modelling and assessment of impacts of elevated CO_2 concentration and related changed climatic conditions on yield
4. estimation of the change of wheat production potential
5. sensitivity analysis of wheat model predicted yields to specific meteorological variables using a combination of experimental and simulation procedures.

RESULTS AND DISCUSSION

1) Parameterization and validation of the model: CERES-Wheat as a dynamic process growth model was specified and validated for two sites in the wheat (Kroměříž - 49^{o}18´ N,

17^{o} 23´ E, 204 m above the sea level) and maize (Žabčice 49 ^{o}01´ N, 16 ^{o} 37´ E, 179 m) growing regions of the Czech Republic. Input data for model simulation was fixed by the method using CERES models (IBSNAT, 1988) and consecutively parameterized to the model required form.

Meteorological inputs in the model are represented by the daily data as: maximum and minimum air temperature (°C), global radiation sum ($MJ.m^{-2}.day^{-1}$) and sum of precipitation (mm). All the data were measured at the classic and automatic meteorological stations in Kroměříž and Žabčice.

Pedological inputs include physical and chemical characteristics in the soil input data set. The data required for a model simulation are following: Bulk and specific density, organic carbon, Al saturation, porosity, soil water limits (wilting point, saturated soil water content, field water capacity), coarse fractions, amount of total nitrogen, NO_3 and NO_4, phosphorus, potassium, magnesium, pH_{H2O} and $pH_{KCl.}$ All the parameters were assigned for the individual soil levels from the soil pit.

CERES-Wheat use ***physiological characteristics*** in different forms as one of the needed inputs. There are six genetic coefficients, which describes the physiological processes (photosynthesis, respiration, and others). They were determined by the experiences of the experts of Agricultural Research Institute, Ltd. in Kroměříž and the results of THORNTON *et al.*, (1991) publication.

Management (cultivation) input data set - management input data such as organic fertilizers, the type of soil cultivation, mineral fertilizers usage, protect mean, and other management variables such as sowing date, previous crop, plant density or irrigation schedules. Data was determined by the daily agrotechnical control.

The grain yields were simulated by the CERES-Wheat growth models which is a 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 parameters. Data from nineteen years was evaluated. The results were compared with observed grain yields.

Validation is the second important step after parameterization to prove the model. The results of validation are represented in Fig. 1.

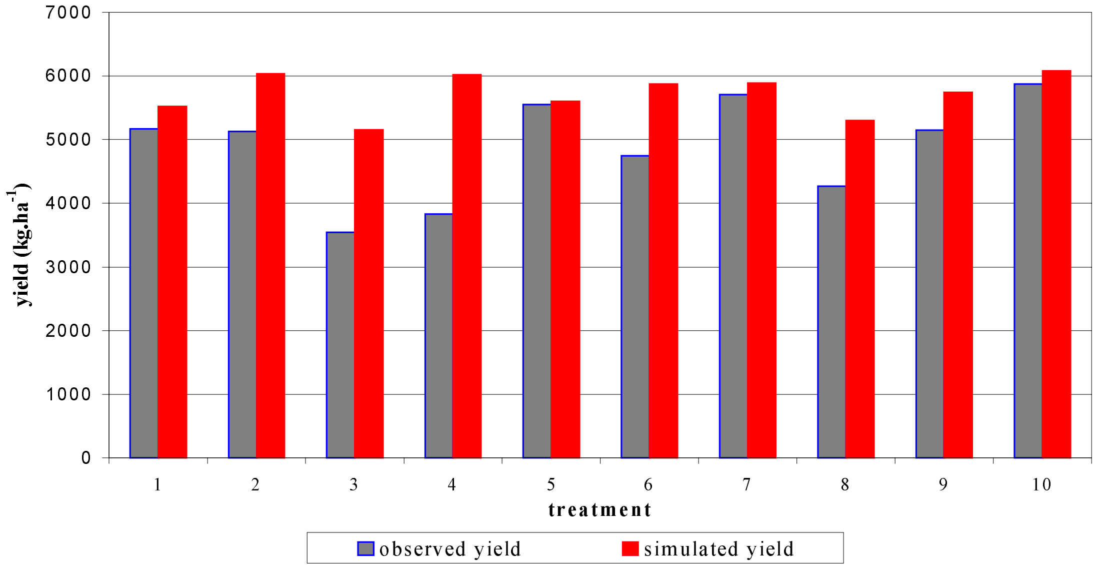

Fig.1: Validation of the CERES – Wheat model for winter wheat Samanta variety, blue column – observed yield, red column - simulated yield.

Model validation means correspondence between observed and simulates results. The probability, of the differences between the predicted and observed yield are not more than 15%, should be at least 80% (HUNKÁR, 1994) for most practical applications. Treatments 1, 2, 5, 7 and 10 got the high agreement between observed and simulated wheat yield (Fig.1). The harvest lost, damage of the canopy by the torrent rains or pest and diseases can explain a small difference in simulated yield. Treatments 3, 4, 6 and 8 did not reach such satisfiable agreement and validation was not successful for them. There was spring barley as previous crop in all cases where appeared *Psammotettix alienus* in the grain.

Table 1: Field experiment of winter wheat (Samanta variety) - overview of the treatments

Winter wheat – Samanta						
				Nitrogen amount		
Variety	Previous Crop	Planting Day	Amount Grain.m^{-2}	Basic kg N.ha^{-1}	Regeneration kg N.ha^{-1}	Production kg N.ha^{-1}
1	ALFAALFA	I	250	40	-	-
2	ALFAALFA	I	250	40	40	40
3	BARLEY	I	250	40	-	-
4	BARLEY	I	250	40	40	40
5	ALFAALFA	II	350	40	-	-
6	BARLEY	II	350	40	40	40
7	ALFAALFA	II	350	40	40	40
8	BARLEY	II	350	40	-	-
9	CORN	III	500	40	-	-
10	CORN	III	500	40	40	40

2) Generating of synthetic data sets by a weather generator for present and changed conditions: Met&Roll is a freely available 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). 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 of wheat yield 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.

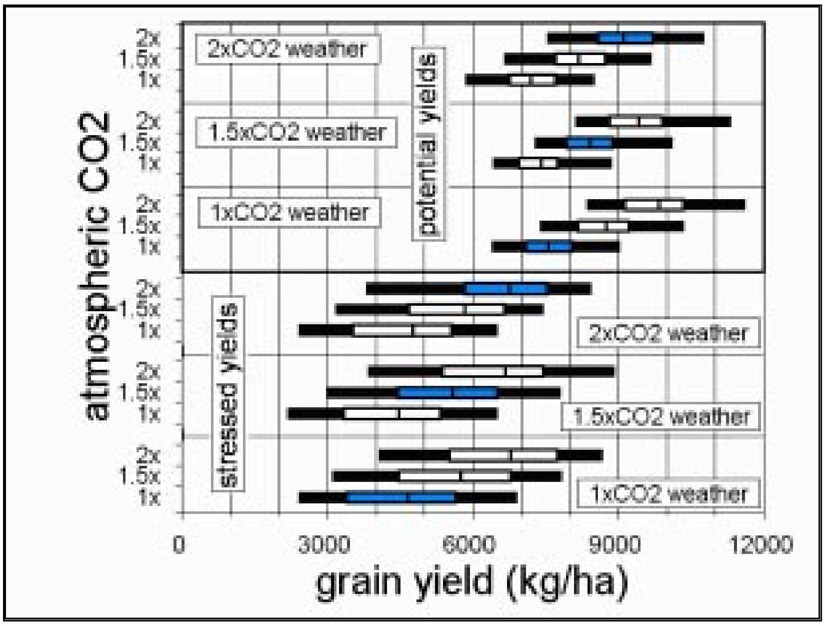

Fig. 2: Potential (water and N are non-limiting) and stressed (water and N routines are "switched on") yields simulated with generated weather. Bars represent quantiles (5^{th}, 25^{th}, median, 75^{th}, 95^{th}) from 99 year simulations

The results are following: Combination of direct and non-direct influence of higher CO_2 concentration will increase the simulated outputs of wheat yield. The potential yield will increase by around 17% the stressed yield will increase by 31% in 2xCO_2 climate. Non-direct impacts of climate change have slightly negative effect but combined impact (direct and non-direct influence) give higher yield compare to present climate. The potential level shows a similar trend. Compare to the C4 crops the reaction of wheat (C3) to rising CO_2 is more intensive in utilization of such an amount of CO_2 in perfect less biochemical cycle of photosynthetic assimilation. Surprisingly, the available water will not be the limiting factor for wheat.

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. Production potential of wheat (ratio between stressed and potential yield) will increase from 59% (1×CO_2 climate) to 64 % (1.5×CO_2 climate) to 69 % (2×CO_2 climate). Potential yield will be influenced less than water limited yield by the outputs from the ECHAM 3/T42 model (Fig.2).

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.

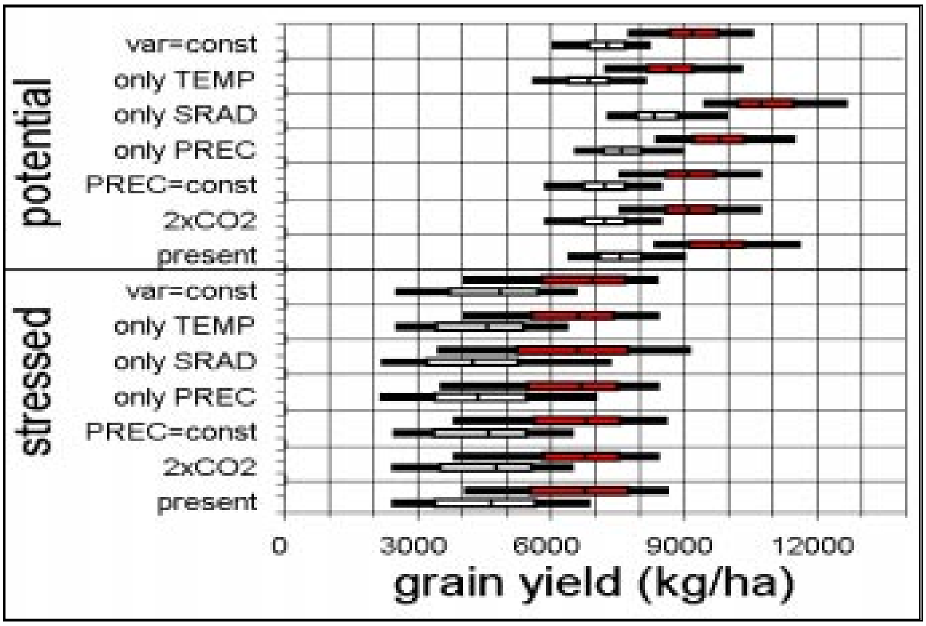

Fig.3: Sensitivity analysis for yield in changed climate conditions. The bars represent quantiles (5th, 25th, median, 75th, 95th) from 99-year simulations.

The set of scenarios used in the sensitivity analysis include:

♦	present	parameters of the WG are derived from observed series (1961-1990)
♦	2×CO_2	parameters of the WG are modified according to GCM-based scenario
♦	PREC = const	same as "2×CO_2" 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×CO_2" but variances of *SRAD*, *TMIN* and *TMAX* are unmodified

Generally changes in meteorological variables derived from climate scenarios resulted in lower crop yields regardless of water and N availability. Exceptions are changes in solar radiation and precipitation at optimal water and N supply.

CONCLUSIONS

This contribution describes the evaluation of climate change impacts on wheat yield. The long term field experiments create the database for wheat growth model calibration and validation. The real meteorological data was replaced by synthetic series generated by stochastic weather generator. Firstly, the parameters of the generator were derived from the observed series and are used to generate weather series representing present climate; secondly, parameters of the generator are modified in accordance with climate change scenario to generate series representing changed climate. This approach allows to perform detailed sensitivity analysis to changes in statistical structure of weather series. For each sensitivity scenario, the 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 of the wheat production potential (ratio of stressed to potential yields) was computed as an objective index of changing weather condition on wheat yields.

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ABSTRAKT

V příspěvku jsou posouzeny dopady změny klimatu na pšenici ozimou. Na základě polních experimentů byla provedena kalibrace a evaluace růstového modelu CERES-Wheat jehož vstupní meteorologické údaje byly nahrazeny údaji syntetickými, které jsou vytvořeny pomocí stochastického meteorologického generátoru. Parametry generátoru byly 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. Byla provedena citlivostní analýza pro posouzení významu změny jednotlivých meteorologických prvků v produkčním procesu pšenice ozimé.

KLÍČOVÁ SLOVA: pšenice, model CERES-Wheat; stochastický meteorologický generátor, změna klimatu; výnos

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