CALIBRATION AND VALIDATION OF THE CROP GROWTH MODEL WOFOST FOR SPRING BARLEY IN CONDITIONS OF THE CZECH REPUBLIC

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One of the possible ways to estimate the effects of the expected climate conditions on the growth, development and yield of crops is the use of the crop growth models. The aim of submitted study was calibrated and subsequently validated the crop growth model WOFOST for spring barley (cultivar "Tolar") in three different soil-climate locations in the Czech Republic - at the experimental stations in Lednice (48° 48′ 51″ N, 16° 48′ 46″ E, altitude 180 m), in Věrovany (49° 27′ 39″ N, 17° 17′ 42″ E, altitude 210 m) and in Domanínek (part of Bystřice Pernštejnem, 49° 31′ 42″ N, 16° 14′ 13″ E, altitude 530 m). A multi-year field experiment data for calibration and validation were provided from the Central Institute for Supervising and Testing in Agriculture (SIAST). The calibration for Lednice, Věrovany and Domanínek was performed using 4 growth seasons from each stations, the subsequent validation was performed based on 3 growth seasons from each station. Namely observed and simulated phenological phases and size of grain yields were compared. Evaluation of agreement between observed and simulated data was done using selected statistical indicators: root mean square error (RMSE) as a parameter of average magnitude of error and the mean bias error (MBE) as an indicator of systematic error. According to the statistical index RMSE for the flowering phenological phase the crop growth model WOFOST showed 3 days error in both calibration and validation; for maturity, the RMSE was 7 days for both calibration and validation. The average RMSE for the yields was 1.6 t.ha^{-1} for calibration and 1.4 t.ha^{-1} for validation. According to the statistical index MBE for the flowering phenological phase, the crop growth model WOFOST showed 1 day earlier estimates in calibration and to the day in validation. There was also to the day in calibration and validation for maturity. According to the MBE, the crop growth model WOFOST overestimates the yield by 1.2 t.ha^{-1} for calibration and overestimates the yield by 0.7 t.ha^{-1} for validation.

Keywords: crop growth model, spring barley, calibration, validation

INTRODUCTION

The temperature and the concentration of greenhouse gases (CO_2) are increasing (e.g., IPCC, 2013, Amthor, 2011). Whereas we can expect changes within the quality and quantity of agricultural production. One of the ways to anticipate the effect of climate change on crop yields in different soil-climatic conditions is the use of crop growth models. The downside of the growth models is their oversimplifying of the simulated systems (Žalud, 2008). In this paper, the aim is calibration of crop growth model WOFOST for spring barley (cultivar "Tolar") in three different soil-climate locations in the Czech Republic - at the experimental stations in Lednice (48° 48′ 51″ N, 16° 48′ 46″ E, altitude 180 m), in Věrovany (49° 27′ 39″ N, 17° 17′ 42″ E, altitude 210 m) and in Domanínek (part of Bystřice Pernštejnem, 49° 31′ 42″ N, 16° 14′ 13″ E, altitude 530 m), based on observed and measured data from the Central Institute for Supervising and Testing in Agriculture (SIAST).

Spring barley is the second most cultivated cereal in the Czech Republic. It is used mainly for malting (Černý, 2007).

The crop growth model WOFOST (World Food Studies) is a simulation model for the quantitative analysis of the growth and production of annual field crops (Diepen, 1989).

To use a growth crop model WOFOST for such a purpose, calibration and subsequent validation must be performed. To calibrate the crop growth models, quality datasets are required. These datasets consist of the following 4 basic dataset groups:

1. crop species and cultivar characteristics
2. meteorological data (daily value: precipitation (mm), maximum and minimum air temperature (°C), irradiation (kJ.m^{-2}), mean wind speed (m.s^{-1}) and vapour pressure (kPa),
3. soil conditions (soil water retention e.g., soil moisture content at wilting point (cm^{-3}.cm^{-3}), field capacity (cm^{-3}.cm^{-3}), saturation (cm^{-3}.cm^{-3}), hydraulic conductivity of saturated soil (cm.day^{-1}); hydraulic conductivity e.g., saturated soil (cm.day^{-1}), maximum percolation rate root zone (cm.day^{-1}), and
4. cultivation technology (e.g., term of sowing, term of emergence, term of maturity and term and dose of fertilizing, harvesting).

MATERIALS AND METHODS

The crop growth model WOFOST was applied to three different soil-climate conditions in the Czech Republic: in Lednice, Věrovany and Domanínek (Figure 1).

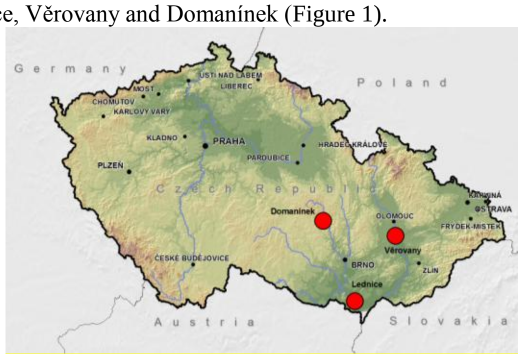
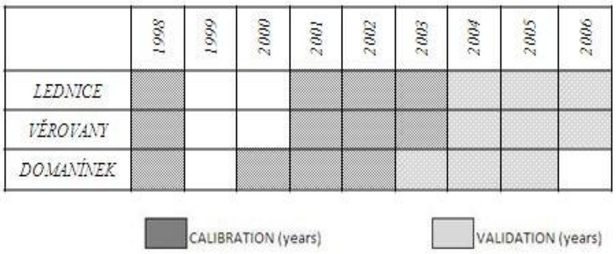


Fig. 1: Map of the Czech Republic with marked interest stations (Lednice, Věrovany, and Domanínek).

The sites represent different climate conditions with Lednice representing a warm and relatively dry spring barley growing region and Věrovany being within the most fertile area of the country with warm climate and mostly sufficient rainfall conditions while Domanínek is the coolest and wettest of all three sites.

For the crop growth model WOFOST calibration and validation purposes, experimental data from a SIAST's (Central Institute for Supervising and Testing in Agriculture) multi-year field experiments in the mentioned locations were used.

Tab. 1: Table of the years that were used for the calibration and validation of the Lednice, Věrovany and Domanínek locations.



The results of the calibration and validation for phenological phases of flowering and maturity and for yield were evaluated using the following statistical parameters: the root mean square error (RMSE), which describes the average absolute deviation between the observed and modeled values, and the mean bias error (MBE) as an indicator of the average systematic error (Davies and McKay 1988).

MBE as the mean bias error and RMSE as the root mean square error can be calculated as follows:

$$\mathrm{MBE} = \frac{\sum_{i=1}^{n}(S_i - O_i)}{n}$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(O_i - S_i)^2}{n}}$$

where *Si* is the estimated value of the variable, *Oi* is the observed value of the variable and n is the number of pairs of observed and estimated values.

RESULTS

The crop growth model WOFOST was calibrated in several steps. The first step was to approximate the conditions of the observed phenological phases (flowering and maturity) by the modeled phenological phases (Figure 2).

The parameters for the length of the vegetative and reproductive development stages were modified in the WOFOST basic settings. The crop growth model WOFOST simulated the gradual phenological development in different soil-climate locations very well. At lower altitudes (Lednice and Věrovany), the onset of barley's phenological phases of flowering and maturity was earlier, thanks to the early onset of suitable conditions for sowing (Figure 2). The second step of calibration was to compare the observed yields with the yields that were simulated by WOFOST. Graphical representations of the modeled and simulated yields can be found in Figure 3. The obtained values of the RMSE and MBE can be found in Table 2.

The major deviation between the observed and modeled yields as depicted in Figure 3 (3.79 t.ha^{-1} observed vs.8.48 t.ha^{-1} estimated) is apparent for 2002 in Domanínek. The experimental logbook, which states that even though the vegetation conditions during the year were favorable, with respect to the sparse vegetation (even on working areas), the yields could not reach the previous year's quality. The experimental logbook does not explain why the vegetation was sparse when the vegetation conditions were favorable in 2002. Therefore, we can only suppose, that something could have negatively affected the real barley canopy experiment, possibly an agrotechnical error, bad conditions during sowing or damage to the crop in a way that is not simulated by a the WOFOST model.

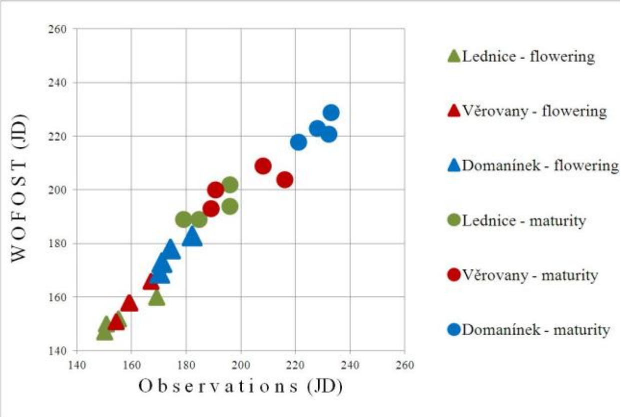


Fig. 2: Calibration – the comparison of the observed and modeled onset of the phenological phases of flowering and maturity for the cultivar "Tolar" at Lednice, Věrovany and Domanínek using the growth model WOFOST. JD – the number of day from the beginning of the year.

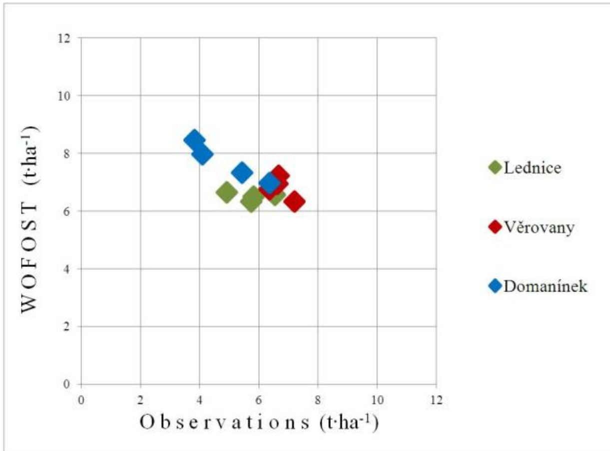


Fig. 3: Calibration - comparison of the observed and estimated yields for the cultivar "Tolar" at Lednice, Věrovany and Domanínek using the growth model WOFOST.

Tab. 2: The evaluation of calibrations according to the statistical parameters MBE (Mean Bias Error) and RMSE (Root Mean Square Error).

MBE			
	Flowering (days)	Maturity (days)	Yields (t·ha^{-1})
Ledncie	2	-6	2.80
Věrovany	-2	1	0.13
Domanínek	-4	5	0.79
Ø	-1	0	1.24
RMSE			
	Flowering (days)	Maturity (days)	Yields (t·ha^{-1})
Ledncie	2	7	3.22
Věrovany	2	8	0.58
Domanínek	5	6	1.01
Ø	3	7	1.60

For flowering the MBE was estimated as -1 days at the average for all stations. The RMSE results were best for Lednice and Věrovany (2 days) and worst for Domanínek (5 days). The onset of phenophase maturity was, according to the statistical evaluation, worse than the onset of the flowering phenophase, ranging from -6 to 5 days.

In addition, the study Rötter et al. (2012) presented the calibration results of the spring barley's phenology and shows some discrepancies with the observations. The mentioned study, which compared 9 crop growth models, including WOFOST, with spring barley's growth and development, includes the observation results from experiments that were carried out in several European countries. Flowering did not correspond to reality by ± 11 days or to maturity by ± 12 days. Not even the simulated yield was satisfactorly by any of the models. In WOFOST, the yield was systematically mostly overestimated. The study Rötter et al. (2012) stated that the reason for fairly systematic overestimation by WOFOST is the assumption that at no time nutrients are yieldlimiting.

Based on the satisfactory results of the crop growth model WOFOST calibration, the verification of this model followed in the form of the model validation. For the calibrated crop growth model, similar experimental data from Lednice, Věrovany and Domanínek from other experimental years served as the input. The validation results are presented Figure 4 and 5 and Table 3.

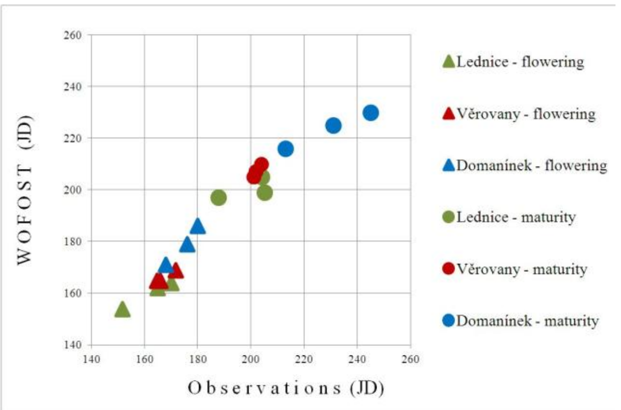


Fig. 4: Validation – the comparison of the observed and modeled onset of the phenological phases of flowering and maturity for the cultivar "Tolar"at Lednice, Věrovany and Domanínek using the growth model WOFOST. JD – the number of day from the beginning of the year.

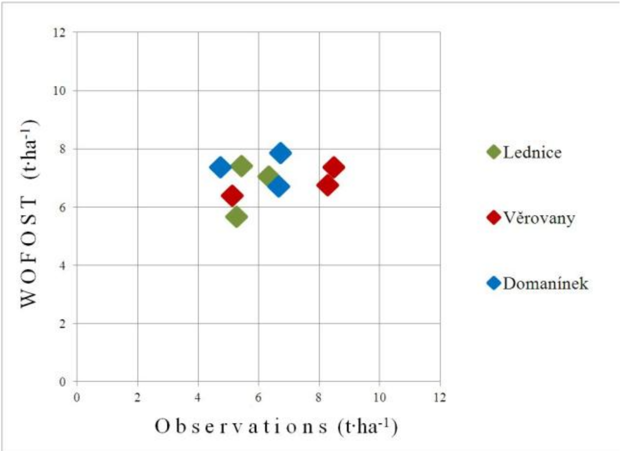


Fig. 5: Calibration - comparison of the observed and estimated yields for the cultivar "Tolar"at Lednice, Věrovany and Domanínek using the growth model WOFOST.

Tab. 3: The evaluation of validation according to the statistical parameters MBE (Mean Bias Error) and RMSE (Root Mean Square Error).

MBE			
	Flowering (days)	Maturity (days)	Yields ($t \cdot ha^{-1}$)
Lednice	4	-6	1.30
Věrovany	-1	5	-0.43
Domanínek	-2	1	1.07
Ø	0	0	0.65
RMSE			
	Flowering (days)	Maturity (days)	Yields ($t \cdot ha^{-1}$)
Lednice	4	9	1.67
Věrovany	1	5	1.31
Domanínek	4	6	1.27
Ø	3	7	1.42

The best results were obtained for Věrovany, where the MBE was only 1.5 day. The RMSE was an average of 3 days, same as in the calibration. The onset of the phenological phase maturity for validation was, according to the statistical evaluation, the same as for calibration and again was worse than the onset of the flowering phenological phase. The deviations range fluctuated from -6 to 5 days. The best results were for Věrovany, and the worst results were for Lednice. The closest simulated yield to that of the experiments was in Věrovany.

CONCLUSION

When calibrating and validating the crop growth model WOFOST for spring barley, in particular the "Tolar" cultivar, satisfactory results both in phenology and yield were achieved compared to those of similar foreign studies or of different data samples. The gained experience from the calibration and validation of the crop growth model WOFOST and the obtained results are a good starting point for the further use of this model e.g. in connection with climate change scenarios.

Acknowledgement

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