CALIBRATION OF THE CROP GROWTH MODELS FOR WINTER WHEAT

Pohanková E.[1, 2], Trnka M.[1, 2], Hlavinka P.[1, 2], Takáč J.[3], Žalud Z.[1, 2]

[1]Department of Agrosystems and Bioclimatology, Faculty of Agronomy, Mendel University in Brno, Zemedelska 1, 613 00 Brno, Czech Republic

[2]Global Change Research Centre, Czech Academy of Sciences, Bělidla 986, 4a, 603 00 Brno, Czech Republic

[3]Soil Science and Conservation Research Institute, Gagarinova 10, 827 13 Bratislava, Slovak Republic

E-mail: Eva.Pohankova@seznam.cz

ABSTRACT

Calibration of the crop growth models DAISY and HERMES was based on experimental results from the Experimental station in Domanínek (49°31,470´N, 16°14,400´E, altitude 530 m a.s.l.). Crop parameters of winter wheat, represented by cultivars Etela and Bohemia, were calibrated. Experimental data (included observations within field trials with two different sowing dates and two nitrogen fertilization levels) from the year 2012 were used for calibration. Evaluation of agreement between simulated and observed data was done using selected statistical indicators, e.g. the 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. Namely measured and simulated leaf area development, phenological phases, soil moisture content and yields were compared. According to the statistical parameter MBE the average simulated flowering by DAISY fit the mean observations and it was slightly underestimated by 0.5 days using HERMES. Also maturity was estimated very slightly earlier (0.5 and 0.8 days on the average) using DAISY and HERMES respectively. DAISY overestimated yields by 0.89 $t \cdot ha^{-1}$ and HERMES overestimated yields by 0.57 $t \cdot ha^{-1}$. According to the statistical parameter RMSE the average error within DAISY results was 4.5 days for flowering, 3.5 days for maturity and 1.03 $t \cdot ha^{-1}$ in yield. The RMSE for HERMES model was 5.0 days for flowering, 4.3 days for maturity and 0.79 $t \cdot ha^{-1}$ in yields.

Key words: the crop growth model, winter wheat, field experiment

Acknowledgments: This study was conducted with the support of project NAZV (National Agency of Agricultural Research) QJ1310123, "Crop modelling as a tool for increasing the production potential and food security of the Czech Republic under Climate Change" and of project Internal Grant Agency, FA MENDELU, No. TP 10/2013 "Study of some factors affecting implementation of the biological potential of agricultural crops".

INTRODUCTION

The concentration of greenhouse gases (CO_2) is increasing. The atmospheric CO_2 is a key source of carbon for plants (Amthor J. 2011) and its increased concentration in the atmosphere accelerates photosynthesis, increases yield and the amount of biomass. It also effects the stomata activity that are more closed due to the easier access. The transpiration is being reduced, the stomatal conductance decreases and the plants use water more effectively (Dhakhwa G.B. 1997). However, the plant growth and development is also affected by meteorological elements (temperature, precipitation and global radiation) and the increase in temperature shortens the plant growth period and the duration of phenological phases (e.g. Batts G.R. 1997), which results in an accelerated development and in a decrease in yield. Whether the crop yield is more affected by the positive fertilization effect caused by CO_2 or by the negative effects of the increase in temperature and the change of other meteorological elements, can be decided virtually only by using the following two methods: 1. Conducting the controlled atmosphere experiments with conditions corresponding to the anticipated climatic conditions, which are the results of time-limited field experiments that cannot be applied on larger areas; 2. Applying the growth models that attempt to approximate the consequences of the climate change on the exchange of substances between the plant and its environment. The downside of the growth models is their oversimplifying of the simulated systems (Žalud Z. et al. 2008). In this paper, the growth models DAISY and HERMES being calibrated based on the experimental data from a 2012 winter wheat (the most cultivated cereals in the Czech Republic) field experiment.

MATERIAL AND METHODS

Crop growth models DAISY and HERMES simulated crop growth, soil temperature regime, water regime, the balance of organic matter and nitrogen dynamics on the basis of information about land management and weather data. DAISY is a Danish agro-ecological simulation model (Hansen S. et al. 1990). HERMES is a German agroecosystem model (Kersebaum K.C. 2011). The input data required include: meteorological data to calculate the reference evapotranspiration ET0 (this paper uses the Penman-Monteith calculation), (Allen R.G. et al. 1998), i.e. average daily air temperature (° C), global radiation ($MJ \cdot m^{-2}$), daily precipitation (mm), wind speed ($m \cdot s^{-1}$), vapour pressure or relative humidity (%); the granulometric composition of soil, bulk density of soil, humus content, C: N ratio, hydraulic conductivity of soil and soil retention curve parameters; agronomical measures data (terms of plowing, fertilizing, seeding, irrigation, harvesting) and crops data – the basic characteristics of the crop which are being simulated. The recalibration lied chiefly in the modification of phenological phases. Models distinguish among leaves, stems, storage organs and roots of plants.

Field experiment: The experimental site is an area with the altitude of 530 m and was established on standardized plots (1,5 x 8 m). Field experiments consisted of eight variants (1, 2,…, 8) in three repetitions (A, B ,C). The variants differ from each other by the combination of two cultivars (Etela and Bohemia), two sowing dates and two different fertilization doses.

Tab. 1 Description of field experiment for winter wheat in 2012

Variant	1	2	3	4	5	6	7	8
Cultivar	Etela	Etela	Etela	Etela	Bohemia	Bohemia	Bohemia	Bohemia
Sowing (2011)	5.10.	5.10.	19.10.	19.10.	5.10.	5.10.	19.10.	19.10.
N ($t \cdot ha^{-1}$)	60	60+20	60	60+20	60	60+20	60	60+20

For three variants (1, 2, 3), the plots were duplicated. One was sampling plot, the other one harvesting. In harvesting plots, two sensors TDR to measure the soil moisture to the depth 30 cm were placed. Once a week, the leaf area index was measured with a SunScan (Delta-T Devices, UK). From the sampling plots, the samples of aboveground biomass (6x) and soil samples during the growing season were taken. In the aboveground biomass, dry matter content per 1 m^2 and the content of nitrogen in the plant were always determined. The soil samples were collected gravimetrically to the depth of 30 cm (5x). They were used for calibration of TDR sensors. The first soil sampling was carried out before sowing. It served to determine the initial conditions and the content of mineral nitrogen in the soil layers. We carefully observed the beginning and the course of the phenological phase, crop health, main yield parameters and yield. Field experiment was monitored by a meteorological station.

To the statistical evaluation of the relationship between the modelled and measured quantities, the following parameters were used: the mean bias error (MBE) as an indicator of the average systematic error and root mean square error (RMSE) which describes the average absolute deviation between the observed and modelled values (Davies J.A. and McKay D.C. 1988). The measurement units are t·ha^{-1} for yield and days for the phenological phases.

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

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

Si... estimated value of the variable
O_i … observed value of the variable
n … number of pairs of observed and estimated values

RESULT AND DISCUSSION

The crop growth models were calibrated in several steps. The first step was to approximate the conditions of modelled phenological phases to the phenological phases observed. The experiments are represented by two cultivars, each having been calibrated separately. The parameters for the length of the vegetative and reproductive development stages were modified within the calibration of DAISY. In HERMES, temperature sums corresponding to each phenological phases were gradually modified. Calibration results are graphically illustrated by Figures 1, 2, 3 and 4. The achieved values of MBE and RMSE are shown in Table 2 and 3.

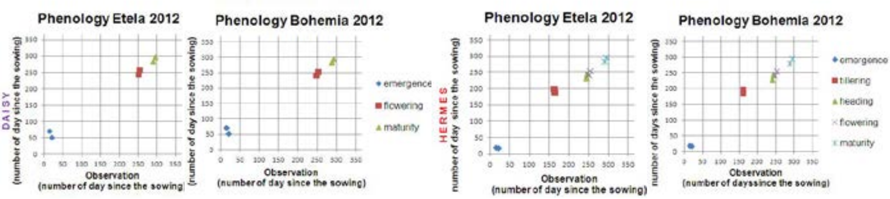

Fig. 1 The comparison of the observed and modelled onset of phenological phases of winter wheat.

The second step of calibration was to compare real and simulated yields in each variant of the experiment. Nor HERMES, neither DAISY can distinguish between the lower and higher levels of fertilization in the expected yields.

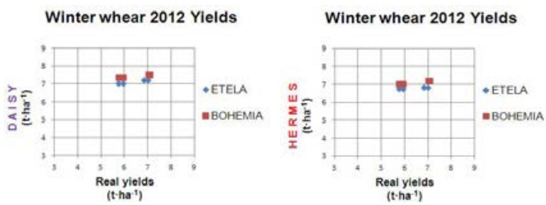

Fig 2. Comparison of observed and estimated winter wheat yields in 2012.

DAISY and HERMES have slightly overestimated the yield for winter wheat. This overestimation could be correct, as the growth model is unable to take into consideration the occurrence of weather disasters (e.g. storms) or diseases and pests.

Tab 2. Evaluation of the calibration according to the statistical parameter MBE

Crop	DAISY MBE			HERMES MBE		
Winter wheat 2012	Flowering (days)	Maturity (days)	Yields ($t \cdot ha^{-1}$)	Flowering (days)	Maturity (days)	Yields ($t \cdot ha^{-1}$)
Etela var. 1-4	0	0.5	0.78	-1.0	-1.0	0.44
Bohemia var. 5-8	0	0.5	1.00	0	-0.5	0.71
2012 Ø MBE	**0**	**0.5**	**0.89**	**-0.5**	**-0.8**	**0.57**

The DAISY model estimated the winter wheat flowering season precisely, regarding maturity, it was 0.5 days ahead, and overestimated the yield gain by 0.89 $t \cdot ha^{-1}$. HERMES was 0.5 days ahead for flowering, 0.8 days ahead for maturity and it overestimated the yield gain by 0.57 $t \cdot ha^{-1}$.

Tab 3. Evaluation of the calibration according to the statistical parameter RMSE

Crop	DAISY RMSE			HERMES RMSE		
Winter wheat 2012	Flowering (days)	Maturity (days)	Yields ($t \cdot ha^{-1}$)	Flowering (days)	Maturity (days)	Yields ($t \cdot ha^{-1}$)
Etela var. 1-4	25.0	12.5	0.82	26.0	17.0	0.46
Bohemia var. 5-8	16.0	12.5	1.28	25.0	20.5	0.78
2012 Ø RMSE	**4.5**	**3.5**	**1.03**	**5.1**	**4.3**	**0.79**

According to the statistical parameter RMSE, the average so called mean square error of the growth model DAISY for winter wheat was 4.5 days for flowering, 3.5 days for maturity and 1.03 $t \cdot ha^{-1}$ for yield. The average model error of HERMES was 5.1 days for flowering, 4.3 days for maturity and 0.79 $t \cdot ha^{-1}$ for yield. The study conducted by Palosuo T. et al. (2011) compared several crop growth models with the growth and development of the given crop, where the results of the observations from several European countries were included. They also noticed differences between the simulation and the actual observation. Within mentioned study the best performance regarding winter wheat yield estimation was for DAISY and DSSAT, for which the RMSE values were lowest (1.4 and 1.6 $t \cdot ha^{-1}$ respectively). In the study conducted by Trnka M. et al. (2004) crop model CERES-wheat was calibrated and tested within 7 Czech locations while mean deviation between simulated and observed values of the anthesis and maturity was less than 8 days.

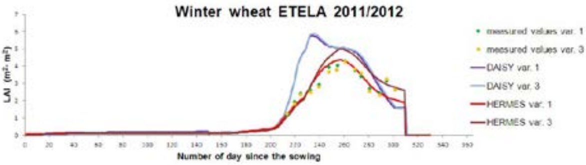

Fig 3. Comparison of the estimated LAI with observed values for Variant 1 with normal agrotechnical term of sowing and with 14 days delayed sowing date for Variant 3

The crop growth models relatively satisfactorily estimate the dynamics of the leaf area in variants 1 and 3 whose sowing date is different. The graphs with LAI values suggest that the growth model DAISY overestimated the development of the leaf area. HERMES, in contrast to DAISY and the data measured by SunScan, takes into account only the leaf area without other area of plants, represented by stems or spikes, which could partially explain the fact that the simulated values of LAI by HERMES are lower than DAISY.

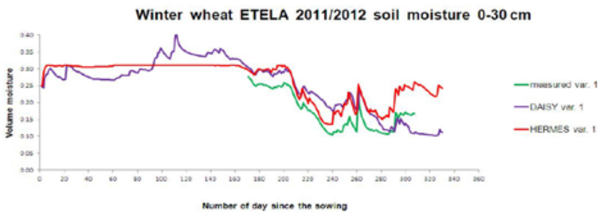

Fig 4. Comparisons between simulated and measured soil moisture for winter wheat in 0-30 cm (Var. 1)

Crop growth models can estimate soil moisture content. The shape of simulated curve relatively satisfactorily corresponds to the shape of curve values measured by sensors TRD. DAISY simulates the movement of water in the soil on the basis of numerical solution of Richards' equation.

CONCLUSIONS

During the calibration of the selected crop growth models DAISY and HERMES for winter wheat in the experimental station Domanínek, satisfactory results concerning the phenological development were obtained. In the case of the estimated yields, neither of the model can satisfactorily explain the variability of the yields observed. Generally, both models showed only small differences in yield among the variants with earlier and the later sowing date in each year. In most cases, the models showed only an insignificant difference in the yield gain of the differently fertilized variants, but it has to be said that the differences in the actually observed yields with respect to the different fertilization were also not significant. The field experiments are still continuing and based on their results, the models are to be recalibrated and validated in the following years.

REFERENCES

AMTHOR, J., 2001: *Effects* of atmospheric CO_2 concentration on wheat yield: review of results from experiments using various approaches to kontrol CO_2 concentration, *in Field Crops Research*, 73:1-34

ALLEN, R. G., PEREIRA, L. S., RAES, D., SMITH M., 1998: Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements, in *FAO Irrigation and Drainage Paper 56*, Rome: FAO.326, IBSN 92-5-104219-5.

BATTS, G.R., MORISON, J.I., L, ELLIS, R.H., HADLEY, P., 1997: Effects of CO_2 and temperature on growth and yield of crop of winter wheat over four season, in *European Journal of Agronomy*, 7:43-52.

DAVIES, J. A. , MCKAY, D.C., 1988: Evaluation of selected models for estimating solar radiation on horizontal surfaces, in *Solar Energy 43*, pp. 153-168.

DHAKHWA, G.B., CAMPBELL, C.L., LEDUC, S.K., COOTER, E.J., 1997: Maize growth:assessing the effect of global warming and CO_2 fertilization with crop models, in *Agricultural and Forest Meteorology*., 87:253-272.

HANSEN, S., JENSEN, H. E., SVENDSEN, H., 1990: DAISY – A Soil Plant System Model. Danish Simulation Model for Transformation and Transport of Energy and Matter in the Soil-Plant-Atmosphere System, edited by *National Agency for Environmental Protection* 272, ISBN 87-503-8790-1.

KERSEBAUM, K.C., 2011: Special *Features of the HERMES Model and Additional Procedures for Parameterization, Calibration, Validation, and Applications: Leibniz-Centre for Agricultural Landscape Research*, edited by Institute for Landscape Systems Analysis, Muencheberg 3, WI 53711-5801

PALOSUO, T., KERSEBAUM, K. C., ANGULO, C., HLAVINKA, P., MORIONDO, M., OLESEN, J. E., PATIL, R. H., et al., 2011: *Simulation of winter wheat yield and its variability in different climates of Europe: A comparison of eight crop growth models*. European Journal of Agronomy 35, 103-114.

TRNKA, M., DUBROVSKÝ, M., SEMERÁDOVÁ, D., ŽALUD, Z., 2004: Projections of uncertainties in climate change scenarios into expected winter wheat yields. *Theoretical and Applied Climatology*, vol. 77: 229-249.

ŽALUD, Z., 2008: *Biologické a technologické aspekty udržitelnosti řízených ekosystémů a jejich adaptace na změnu klimatu - metodiky stanovení indikátorů ekosystémových služeb*, in Mendelova zemědělská a lesnická univerzita v Brně, IBSN 978-80-7375-221-7, pp. 167.