ASSESSING THE IMPACT OF DROUGHT STRESS ON WINTER WHEAT CANOPY BY HERMES CROP GROWTH MODEL

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Abstract: The main aim of this study was evaluate a drought stress effect on winter wheat development, growth (leaf area index), soil moisture and yields. Simultaneously, the ability of Hermes crop growth model to simulate drought stress response was tested. The field trial was established at Domanínek station (Bystřice nad Pernštejnem district, Czech Republic) in 2014. Mobile rain-out shelters for precipitation reduction were installed on the plots of winter wheat in May 2015. Results of this study showed that model is able to reproduce well a soil moisture content and to certain extent the drought stress for grain yields of winter wheat. Using the rain-out shelters (from 19 May to harvest on 6 August 2015), real winter wheat yields were reduced by 1.7 t/ha. The model was able to estimate the average yield with a deviation of 0.15 t/ha (6%) for no stressed variant. Model underestimated the yields for sheltered variant with a difference 0.67 t/ha (71%) on average against observed yields.

Key Words: leaf area index, rain-out shelters, soil moisture, water balance, yields

INTRODUCTION

Winter wheat is the most grown cereal in the Czech Republic. In the years 2014–2015 wheat exceeded the area of 830 000 ha and it was produced 5 274 000 tons of grain yield (ČSÚ 2016, Mikulášová 2015). Drought that hit the Czech Republic in 2015 belong to the most serious historical drought episodes. The occurrence of more frequent droughts may become a major problem in the coming years (Daňhelka et al. 2015). If the temperature rises by 2 °C or more (above late 20th century levels), for the major crops is excepted adverse climate change which will have a negative impact on production increased annual yields variability in many areas (IPCC 2014).

There are a lot of crop growth models used to assessing the impact of a future climate change. Each the crop growth model is unique in architecture, complexity, algorithms and parameterization (Palosuo et al. 2011). Hermes crop growth model belong between wide used, easily accessible and well-documented crop growth simulation model (i.g. Palosuo et al. 2011). It is used for example to cropping systems, soil nitrogen dynamics, to estimate irrigation water demand and predicting yield response to nitrogen fertilization with satisfactory results (e.g. Salo et al. 2015, Graß et al. 2015, Hlavinka et al. 2015).

The main aim of this study was evaluate the drought stress effect on winter wheat using the Hermes crop growth model. Realistically measured parameters of development, growth, soil moisture and yields were compared with the simulated results of model Hermes within sheltered and unsheltered variants.

MATERIAL AND METHODS

Field experiment

Field experiment was established at Domanínek experimental station (49°31'42"N, 16°14'13"E, altitude 560 m) in the season 2014–2015. Mean annual temperature is 7.2 °C and mean precipitation is 609.3 mm within period 1981–2010. This area is characterized by a low soil quality (the soil type dystric cambisol). Soil properties are shown in Table 1.

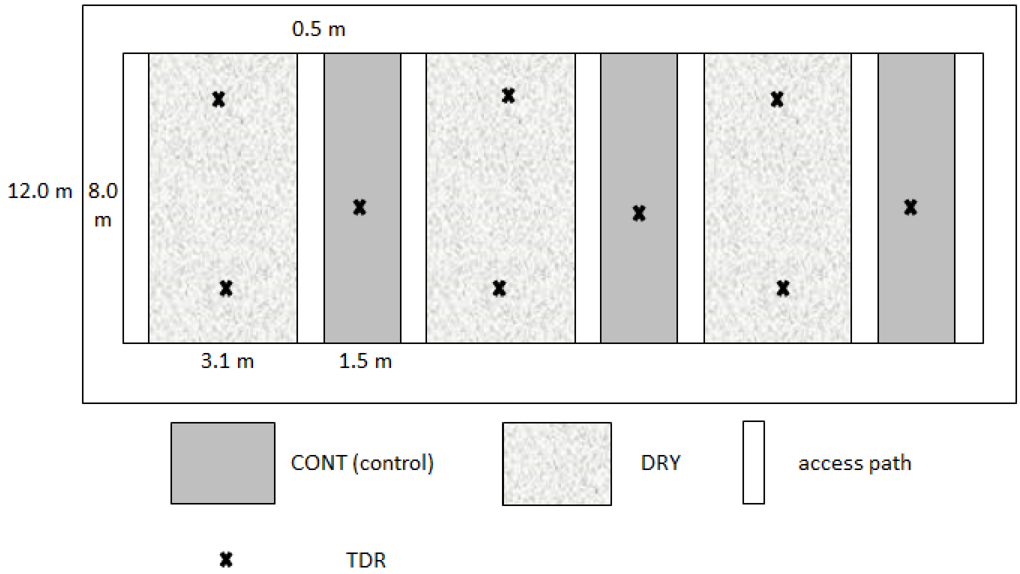
Table 1 Basic soil properties at the experimental site of Domanínek

Borderline [m]	WP [%]	Field water capacity [%]	Soil porosity [%]	Soil type	Soil texture		
					clay [%]	silt [%]	sand [%]
0.0–0.3	8	24	44	silty-loamy sand	8–17	40–50	33–52
0.3–0.4	6	23	39	silty sand	0–8	25–40	52–75
0.4–0.5	6	23	39	loamy sand	8–12	10–40	48–82
0.5–2	2	6	17	loamy sand	8–12	10–40	48–82

Legend: WP – wilting point

The experiment with winter wheat variety Bohemia was set up in 2 variants on 30 September in 2014. The first variant was conducted under natural climatic conditions (abbreviated as CONT, plot size 1.5 × 8.0 m). In the second variant, the drought stress was induced using rain-out shelters (abbreviated as DRY, plot size 3.1 × 8.0 m). Mobile rain-out shelters (size 3.1 × 8.0 m) were installed on the plots of winter wheat on 19 May 2015 and were removed in the harvest day (6 August 2015). To production the shelters a corrugated material (Suntuf CS – clear polycarbonate with two-sided UV filter; trapezius 76/16, thickness 0.8 mm) was used. Each variant was repeated three times (Figure 1).

Figure 1 Field trial map with the position of rain-out shelters (DRY) and TDR sensors for soil moisture measurements



As a basal fertilization 20 kg/ha N (NPK) was applied before sowing (September 2014). 35 kg/ha N regenerative fertilization DASA (nitrogen fertilizer containing sulfur) and 25 kg/ha N regenerative fertilization LAV (ammonium nitrate with limestone) was applied in March 2015 and 60 kg/ha N production fertilizer LAV was introduced into the soil in April 2015. CONT and DRY variants included the same dose of fertilizations.

The leaf area development (leaf area index - LAI) was measured by SunScan (Delta-T Devices, Cambridge, UK) at intervals of 6–21 days during June to August. In harvest parcels were installed TDR sensors (time domain reflectometry, CS 616, Campbell Scientific Inc., Shepshed, UK) to measure soil moisture content (depth 0.3 m) and two TDR sensors were always placed under each of the roofs and another (one sensor) was outside of the roof (control). See Figure 1.

Crop growth simulation model

Assessment of the drought stress was carried out by the Hermes crop growth model (e.g. Kersebaum 2008). It is a process-oriented model for estimating development and growth of the field crops, soil water balance and the dynamics of nitrogen for arable land. The benefit of using Hermes is the ability to work with a relatively small amount of input data sets that are ordinarily available at the farm level (Kersebaum 2011).

Crop growth is capped by water and nitrogen stress. Drought stress is indicated by the ratio of actual and potential transpiration. For this study was selected the Penman-Monteith approach to estimate reference evapotranspiration (Allen et al. 1998, Monteith 1965). Dynamics of soil water is derived from a simple capacity approach (Kersebaum 2011).

Input data sets are divided into three parts: daily weather data (average, minimum and maximum temperature, air humidity, wind speed, precipitation), soil properties (soil nitrogen content, soil moisture, field capacity, wilting point and porosity) and agrotechnical (management) data (tillage, pre-crop, fertilizing, sowing and harvesting). These data were obtained from Domanínek experimental station for the period 2013–2015.

RESULTS AND DISCUSSION

The total rainfall was 93 mm in the Domanínek experimental station from rain-out shelters installation to the harvest. These total rainfall was reduced under drought stress experiment.

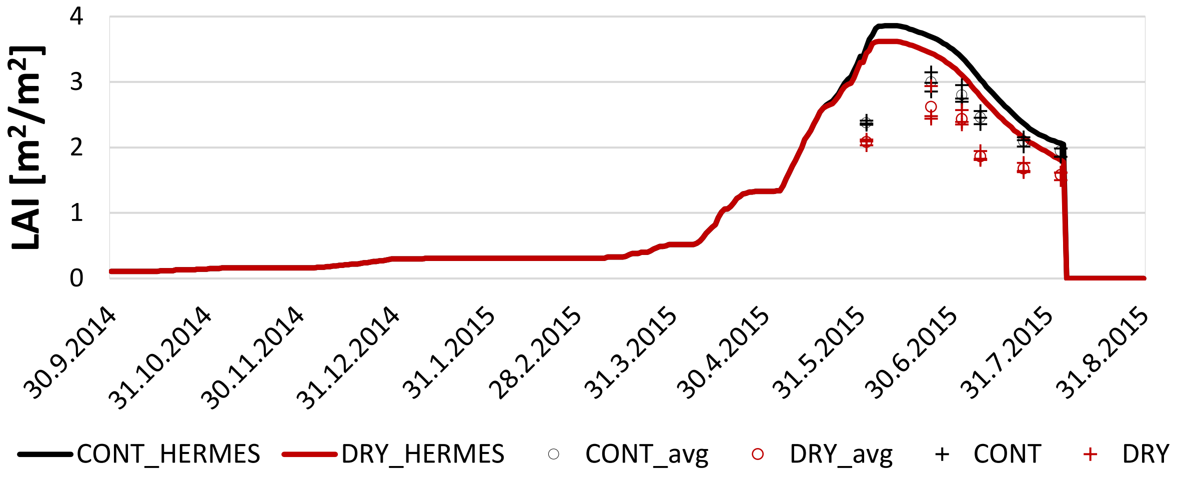
Calibration

The first step to the model adaptation for a variety Bohemia was calibration for crop phenology (emergence, tillering, heading, flowering and maturity). Model was calibrated on the basis of measured and observed data from field experiments. Successive alteration temperature sums leaded to corresponding onset of phenological phases. After calibration, the model showed almost the same results of the phenological phases duration as measured values. On the other hand for phenological phase of maturity model underestimated DRY variant by 11 days.

Leaf area development

From the point of view of leaf area development, crop growth model overestimated that development (Figure 2). It is necessary to mention that the Hermes model simulates only the leaf area, while measuring with SunScan covers a total area of above-ground of plants. Therefore, the measurement points should be above simulated curves. It can be explained by the fact that the year 2015 was considerably dry and wheat canopy was low and had also sparse participation. Otherwise, it is necessary to recalibrate the model data from ongoing measurements to obtain more precise data from the Hermes model. Within Palosuo et al. (2011) study dealing with the comparison between models for winter wheat, the Hermes model led the average. In current study, the crop growth model Hermes is able to evaluate a little bit better the CONT option then DRY variant. However, the differences between CONT and DRY variants are almost similar within the simulated and measured leaf area index. On the other hand, the model captured the growth dynamics of leaf area at similar level as in the Pohanková et al. (2013) study.

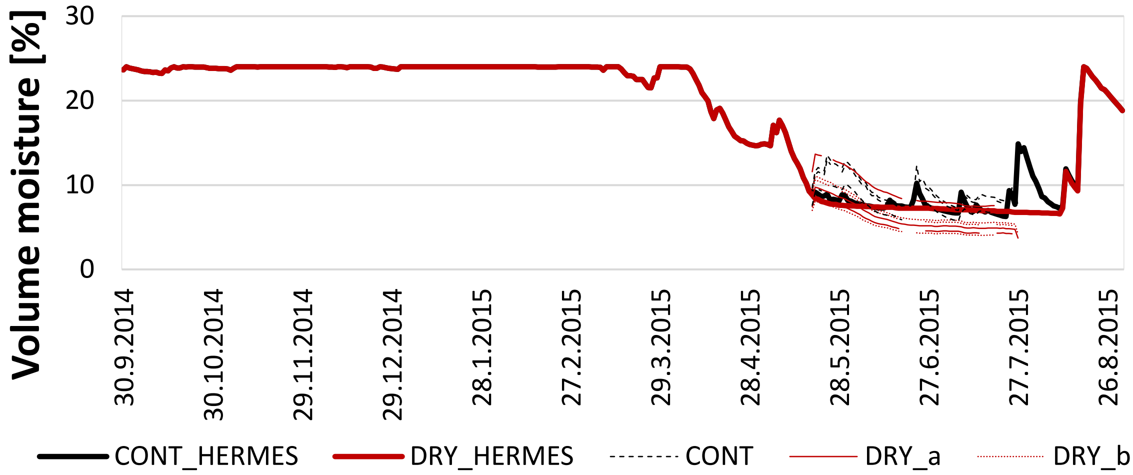
Figure 2 SunScan measurements compared with simulated LAI. The average measured values are indicated with circles and measured values are indicated with crosses.



Soil moisture

Evaluation of the soil moisture estimates using TDR sensors was very accurate. Within DRY variant, modeled data were evaluated as nearly flat curve which confirms waterproof of roofs (Figure 3). Modeled CONT variant depict changes in the soil moisture under the influence of precipitation with good precision as it is compared with the curves of controls. Simulated curves for CONT and DRY variants were sufficiently corresponded to the shape of curve measured values by TDR sensors. Pohanková et al. (2013) study confirmed the accuracy of the Hermes model using in Domanínek locality. Within crop model inter-comparison (e.g. Palosuo et al. 2011 or Rötter et al. 2012), the Hermes model estimated the soil moisture with a pinpoint accuracy.

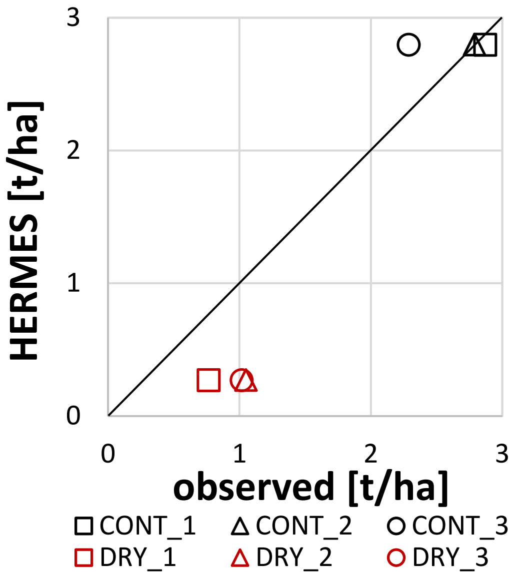
Figure 3 Comparisons between the simulated and measured (under roof and outside) soil water content from 0.0–0.3 m. Control (dashed line) represent measurement outside the roof (CONT). DRY_a and DRY_b depicted TDR sensors which were placed under one roof. Period from sowing to the end of August.



Yields

The impact of a moisture shortage was reflected to the values winter wheat yield by the Hermes model (Figure 4). Model slightly overestimated the yields in an uncovered variant (CONT) in average of 0.15 t/ha (6%) and underestimated the yields in a rain-out shelters variant (DRY) in average of 0.67 t/ha (71%). It may be caused by UV filter presence or by the fact, that model is not able to simulate all kind of stresses (like effect of pest, disease etc.). For example Feng et al. (2007), Kataria and Guruprasad (2012) or Lizana et al. (2009) studies showed the UV radiation which has a significant effect on the wheat yield. Kataria and Guruprasad (2012) study demonstrated the increase yields while the UV-B and UV-A radiation were reduced. Study Lizana et al. (2009) examined again the effect of increased UV-B radiation leading to reducing the yield of 12–20%. In the current study using the rain-out shelters real winter wheat yields were reduced by 1.7 t/ha. For CONT variant, especially first and second parcels, the Hermes model assessed excellently winter wheat yields.

Figure 4 Comparison observed and modeled winter wheat yields for roof versions (DRY) and rainfed parcels (CONT) and repetitions 1 to 3.



CONCLUSION

This study assessed the impact of drought stress on winter wheat canopy by Hermes crop growth model. Under field trial, the winter wheat was exposed drought stress using rain-out shelters. These results were subsequently compared with simulated values.

First, model was calibrated to set a model for the Bohemia variety. Additional step, observed and simulated values of selected parameters were compared to assessing the ability of the model to capture the lack of soil moisture and the resulting effects. Investigated parameters were leaf area index (LAI), soil moisture and yields. Under the evaluation of the leaf area development, the modeled values were overestimated against the measured values. However, curve dynamics was depicted relatively correctly. As far as the measured and simulated soil moisture, results were very similar. Within comparing the yields was found, that the model Hermes overestimated mean yields about 0.15 t/ha for ambient climate conditions. In case of field crops stressed by drought, the model Hermes underestimated mean yield about 0.67 t/ha. This may be implication of two-sided UV filter which the roofs contain since the model does not take into consideration lower of UV radiation due to using Suntuf. The impact of roofs (especially solar UV exclusion effect) on canopy is investigated in a separate experiment in 2016.

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