THE USE OF SOILCLIM AND HERMES MODEL FOR IRRIGATION WATER DEMAND ESTIMATES

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The aim of this study was to simulate hypothetical irrigation water demand for regions of the Czech Republic. For this purpose SoilClim model and HERMES crop growth model were used considering spring barley, winter wheat and maize cultivation. The SoilClim model estimates within the Czech Republic were conducted for grids (500 x 500 m) classified as arable land. The amount of water necessary for keeping the soil moisture at least at 50 % of water holding capacity within the depth 0-40 cm (from sowing to maturity) was quantified. By this way the period from 1981 to 2010 was assessed. HERMES crop growth model was used as second approach. Water demand (to maintain soil moisture at least at 50 % of water holding capacity within the depth 0-40 cm) was estimated for three locations (Lednice, Věrovany, Domanínek) for the periods 1982-2000, 2001-2020 and 2061-2080. Weather series for future climatic conditions were based on selected CMIP3 global circulation models (MPEH5, CSMK3, CGMR, GFCM21, and IPCM4) in connection with Representative Concentration Pathway (RCP) 4.5.

Keywords: soil water holding capacity, water balance

INTRODUCTION

Czech Republic recently experienced a series of drought events with severe impacts within field crop production. The recent drought events may be the result of multi-decadal climate variability or a more general trend. Statistically significant trends of decreasing soil moisture content were found, notably during May and June between 1961 and 2012 (Trnka et al., 2015). The water availability for field crops is very crucial in these months (Hlavinka et al., 2009) and next tendencies to drier conditions could be expected in connection with ongoing climate change as it was reported by several studies (IPCC, 2013; Trnka et al., 2013). Under such conditions there is real concern that extent of necessary irrigations will likely increase in the future as it was indicated e.g. by Riediger et al. (2014) based on example for Nerthern Germany using climate change scenario under RCP 8.5 for the period until 2070. Water and irrigation availability allows certain buffering towards drought appearance to optimize yields level or prevent possible crop failure in some years and it is considered as one of the possible adaptation measures for future climate.

There was observed significant decrease of irrigated area from the year 1989 in the Czech Republic. The reason was restructuring of the whole agricultural sector after velvet revolution. Currently, renovation or new construction of irrigation systems are re-considered due to actual conditions and the projected evolution of climate in the future.

The aim of this study is to show results of state-of-the-art soil moisture model (SoilClim) and crop growth model (HERMES) focused on hypothetical irrigation water demand estimates for selected crops (spring barley, winter wheat and silage maize) under actual and future climatic conditions through the Czech Republic regions.

MATERIALS AND METHODS

First method used for hypothetical irrigation water demand estimates was SoilClim model (Hlavinka et al., 2011) as a modification of the method introduced in FAO-56 Irrigation and Drainage Paper (Allen et al., 1998). This approach was applied for the arable land through the whole Czech Republic. By this way the amount of necessary irrigated water to maintain soil moisture between sowing to maturity at least at 50 % of available soil moisture in soil layer 0-40cm was estimated. The SoilClim model was used in grids (500 x 500 m) with arable lands through the whole Czech Republic. For this purpose spatially interpolated daily weather data from 1981 to 2010 and information about soil water holding capacity for each grid were used. By this way results corresponding to winter wheat, spring barley and silage maize were separately obtained.

Second method was based on using HERMES model (e.g. Kersebaum et al., 2008). This crop growth model is a process-oriented model for estimating crop development and growth, soil water balance, and nitrogen dynamics within arable land. A detailed photosynthesis-respiration approach is used. The advantage provided by using HERMES is its ability to work with a relatively limited set of input data that are usually available at the farm level. Soil-water dynamics estimates are based on a simple capacity approach. The Penman-Monteith approach (Monteith 1965, Allen et al., 1998) for grass reference evapotranspiration estimation was used in connection with crop-specific factors (Kc). Its division into evaporation and transpiration is dependent on leaf area index (LAI). Potential transpiration is distributed to deeper layers using soil-dependent exponential functions. Transpiration is reduced using an empirical function that depends on the water content of the upper soil layer (van Keulen and Seligman, 1987). The generic crop growth module is based on the SUCROS model approach (van Keulen et al., 1982). Dry matter production is driven by intercepted radiation and temperature and is reduced by drought and nitrogen stress. The influence of the CO_2 atmospheric concentration on photosynthesis is included via an approach proposed by Hoffmann (1995) in combination with a mixed Allen/Yu approach (Allen et al., 1998, Yu et al., 2001). In case of this study the HERMES was used for three locations Lednice, Věrovany and Domanínek and two contrasting soils: 1) Chernozem with high water holding capacity (270 mm) and 2) Cambisoil with low water holding capacity (100 mm). Simulations were conducted for the period from 1981 to 2080.

The climate projections for the period 2010-2080 were based on 5 Global Circulation Models (MPEH5, CSMK3, CGMR, GFCM21, and IPCM4) from an ensemble of the 18-member CMIP3 global circulation models. Used projections are for the RCP 4.5 (Representative Concentration Pathway) greenhouse gas concentration trajectory. The simulations were conducted as uninterrupted crop rotations (winter wheat - spring barley - silage maize - winter wheat - winter rape) using procedure described in Hlavinka et al. (2015). Catch crops were cultivated before spring crops. Combination of mineral nitrogen and cattle manure was regularly used. The hypothetical water demand was estimated to maintain soil moisture at least at 50 % of available water in soil layer 0-40 cm and irrigation doses were set-up to 20 mm if the conditions were fulfilled between emergence and maturity.

RESULTS

Results of hypothetical water demand (assumed as irrigation) for spring barley, winter wheat and silage maize based on climatic conditions of the period 1981-2010 through the Czech Republic is captured in Fig. 1. Where the highest irrigation demands were suggested for winter wheat.

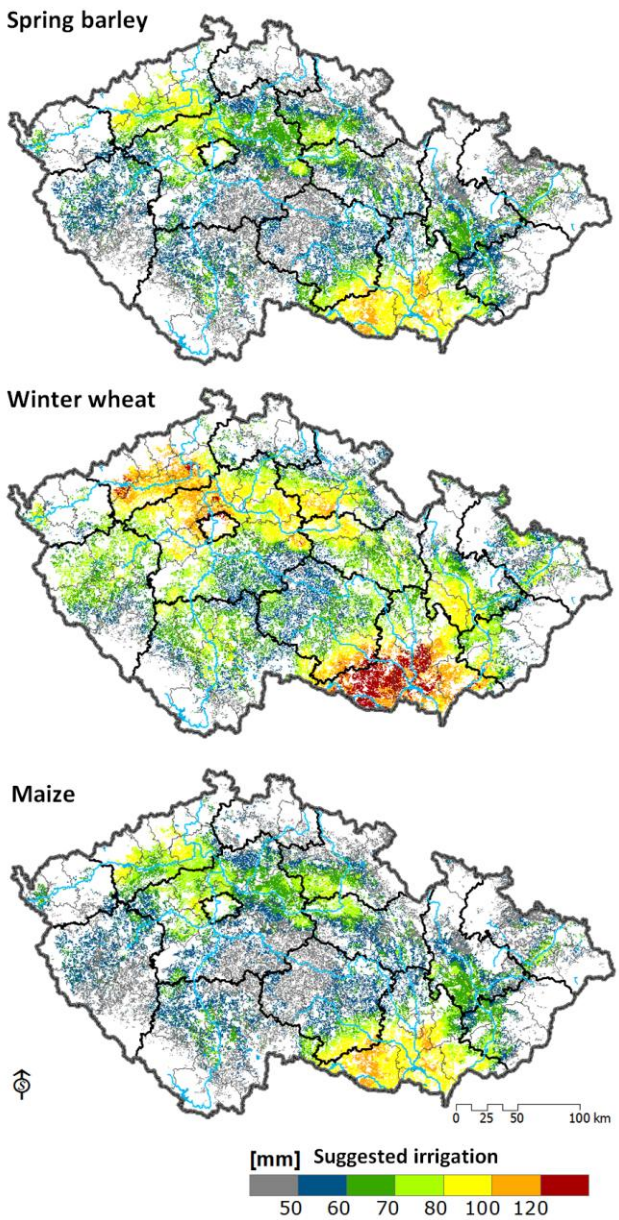
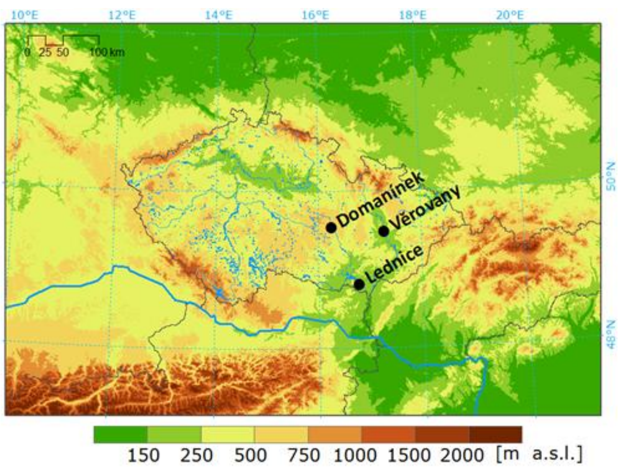


Fig. 1 Amount of hypothetical water demand to maintain soil moisture between sowing to maturity at least at 50 % of available water in soil layer 0-40 cm. The SoilClim model was used in grids (500 x 500 m) with arable lands (colored from grey to red) through the whole Czech Republic. The results for the period 1981-2010 were depicted. In each grid the median from 30 seasons were used. (White areas are grids without arable land.)

The median of suggested irrigation winter wheat demand over 30 years was over 120 mm for Znojmo, Břeclav, part of Brno venkov districts and few smaller areas in Bohemia. The results for spring barley and silage maize based on SoilClim were almost identical, while for highest medians are below 120 mm.

Estimated irrigation amounts by HERMES model for three locations (Lednice, Věrovany, Domanínek) with temperature and precipitation gradient were depicted in Fig 2a,b. The irrigation amounts were simulated for recent period (1982-2000), present (2001-2020) and future period (2061-2080) based on 5 GCMs (CGMR, CSMK3, GFCM21, IPCM4, MPEH5). Moreover mean irrigation effect on achieved yields (t/ha) is presented in Table 1. Based on simulations by HERMES the difference between results for Chernozem with high soil water holding capacity (as soil No. 1) and Cambisol with low soil water holding capacity (as soil No. 2) was quantified from water demand and yields point of view. Higher irrigation and irrigation effectiveness was reported for soil No. 2. The highest increase of absolute yields due to irrigation was reported for Lednice (driest site), driest climatic scenario (GFCM21) and soil with lower water holding capacity. In such cases the average yields increases were estimated at level 1.9, 3.6 and 6.0 $t.ha^{-1}$ for spring barley, winter wheat and silage maize respectively.

a)



b)

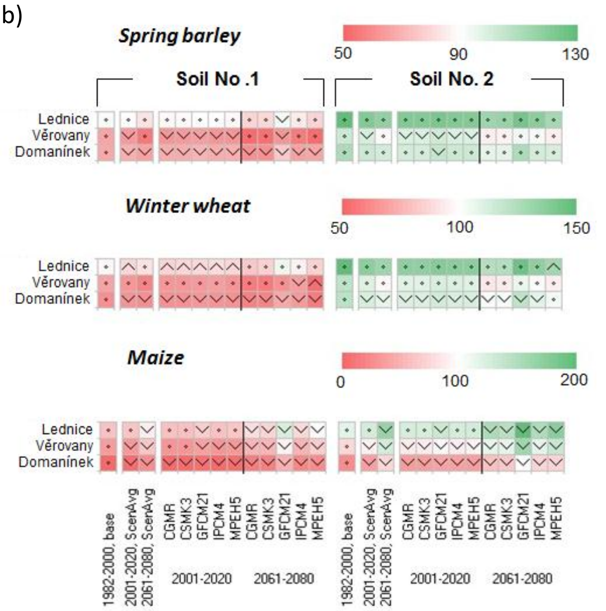


Fig. 2. Location of station Lednice, Věrovany and Domanínek (a) and average suggested irrigation demand for spring barley, winter wheat and silage maize (b). The irrigation amounts were depicted for recent period (1982-2000), present (2001-2020) and future period (2061-2080) based on 5 GCMs (CGMR, CSMK3, GFCM21, IPCM4, MPEH5). For 2001-2020 and 2061-2080 also mean values (as ScenAvg) based on all included GCMs were identified.

Tab. 1 Average yield increase (t.ha^{-1}) in case of assumed irrigation (against the same runs but simulated as rainfed) estimated by HERMES model for periods 1982-2000 and 2061-2080.

			1982-2000	2061-2080				
				CGMR	CSMK3	GFCM21	IPCM4	MPEH5
Spring barley	Soil No. 1	Lednice	0.6	0.1	0.1	1.6	0.3	0.4
		Věrovany	0.1	0.0	0.0	0.2	0.0	0.0
		Domanínek	0.0	0.0	0.0	0.0	0.0	0.0
	Soil No. 2	Lednice	1.7	1.4	1.4	1.9	1.6	1.5
		Věrovany	1.2	0.8	0.8	1.1	0.9	0.8
		Domanínek	1.6	1.1	1.1	1.7	1.3	1.4
Winter wheat	Soil No. 1	Lednice	1.0	0.4	0.5	3.4	1.0	1.2
		Věrovany	0.1	0.0	0.0	0.5	0.1	0.1
		Domanínek	0.0	0.0	0.0	0.0	0.0	0.0
	Soil No. 2	Lednice	2.7	2.8	2.6	3.6	2.8	2.9
		Věrovany	2.1	1.6	1.6	2.4	1.7	1.7
		Domanínek	2.3	2.1	2.0	3.3	2.3	2.6
Silage maize	Soil No. 1	Lednice	0.5	0.7	0.6	3.4	0.8	1.4
		Věrovany	0.2	0.2	0.2	0.9	0.2	0.4
		Domanínek	0.0	0.0	0.0	0.1	0.0	0.0
	Soil No. 2	Lednice	3.3	4.6	4.2	6.0	4.2	5.4
		Věrovany	1.9	3.3	3.3	4.9	3.1	4.0
		Domanínek	0.5	1.6	1.7	3.2	1.9	2.1

CONCLUSION

Based on achieved results could be concluded that the soil water balance and crop growth modeling tools (represented by SoilClim model and HERMES model respectively) can be used for irrigation water demand analysis for several crops (crop specific comparison) and both at regional and local level. The results are important both for strategic decision making to define spatial extend of regions with certain water demand and also for operational decision making when the information about actual conditions and effectiveness of irrigation will be available. It was proved that under current conditions the influence of soil water holding capacity is very important. The irrigation availability can significantly improve the yields level in future especially in drier conditions and dry climatic scenario. Nevertheless, real using of irrigations will depend on combination of many factors (e.g. water and energy price, water source availability, suitability of fields from terrain point of view, cost of production and the willingness of farmers to invest and maintain the infrastructure, etc.) in future. Moreover there is still uncertainty about future climate and which scenario becomes a reality (as crucial condition).

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