Takáč, J., Šiška, B., Nováková, M.: Climate Change Impact on Irrigation Need of Field Crops on Danubian Lowland
. Šiška, B. – Hauptvogl, M. – Eliašová, M. (eds.). Bioclimate: Source and Limit of Social Development International Scientific Conference, 6th – 9th September 2011, Topoľčianky, Slovakia

CLIMATE CHANGE IMPACT ON IRRIGATION NEED OF FIELD CROPS ON DANUBIAN LOWLAND

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Abstract. Evaluation of climate change impacts on soil water regime of field crops was based on simulations by agroecological model DAISY. Irrigation needs were calculated for winter wheat, spring barley, corn maize and sugar beet. Water regimes were simulated in 2 variants: rainfed and water limited irrigation. Irrigation was applied automatically after decreasing of soil water content below 50% of available water capacity for each of evaluated crop. Effect of gradual increase of CO_2 concentration was taken into account for two climate change scenarios (SRES A2 and SRES B2). Increasing of variability and decreasing of soil water content during vegetation period is expected according to the statistical analyses of simulations. According to both emission scenarios consequent increase of potential evapotranspiration and crop water requirements would gradually increase up to time horizon 2071–2100. Increase of irrigation need by 20–155 % was found for field crops in climate change conditions. CO_2 concentration can positively influence productivity of C3 crops due to increase of water use efficiency if water is available in soil profile. On the other hand variability of yields will be influence by more frequent drought episodes. As resulted from the simulations of climate change impacts the shortage of soil water will decline. Number of days with available water capacity below 50% will increase during the growing season of field crops and evoke increase of irrigation needs. The irrigation season will start earlier and will persist for longer time.

Introduction

Climatic conditions become the most important factor influencing variability of field crop yields in Slovakia today. Increase of annual mean air temperature by about 1°C was occurred on most of climatic stations in Slovakia during last century. On the other hand annual precipitations decreased by about 10 % on Danubian lowland during this period. (Lapin et al. 2001). Increase of air temperature and shortage of precipitations create conditions for drought occurrence especially on lowlands of Slovakia. According to outputs of General Circulation Models (GCM) this trend is also supposed for future climate (Šiška & Takáč 2008). Those facts call for analyses of drought occurrence in conditions of climate change on territory of Slovak republic.

According to natural climate variability and the duration of drought several levels of drought can be defined (Hayes et al. 1999; Heim 2002). Climatic water balance was frequently analyzed in many works for evaluation of drought conditions of Central Europe (Tomlain 1997; Dubrovský et al., 2005, Ditmarová et al. 2006; Trnka et al. 2008; Hlásný & Baláž 2008). This index was also used for agroclimatic regionalization of Slovak Republic during period of 1931–1960 (Kurpelová et al. 1975) and 1961–1990 (Šiška & Špánik 2008).

According to GCM there is supposed decrease of soil water content is supposed on lowlands of Slovakia since April till October with gradation in period July - September (Tomlain 1997). During summer season the mean soil water content will decrease below 50% of available water capacity (AWC) up to time horizon of the year 2075 on the southern part of Danubian lowland and Zahorie lowland, and below 60% on East Slovakian and Northern part of Danubian lowlands (Takáč 2001). Irrigation water need will significantly increase in condition of climate change. According to analyses of meteorological data from 10 climatic stations on the territory of Czechoslovakia the increase of monthly mean air temperatures by 1.5°C led to increase of the irrigation water demand by 20 to 35%. The demand is doubled if the temperature rise by about 4.5°C (Kos 1970). Winter wheat and soybean yield modeling in northern Italy (Modena) showed that to keep the present level of yields, 60 to 90 % more irrigation water is required in condition of climate change (Tubiello et al. 2000).

Data and methods

Evaluation of the climate change impacts on soil water regime under field crops was based on simulations by agroecological model DAISY. DAISY is a one-dimensional model simulating water, energy, nitrogen and soil organic matter balance. Crop development and yield is possible to simulate in dependence on crop rotation and various management strategy. DAISY simulates plant growth and development, including the accumulation of dry matter and nitrogen content in different plant parts. The main plant-growth processes considered in DAISY are photosynthesis, respiration, partitioning of assimilates, stress factors and leaf and root development. DAISY allows for building complex management scenarios (Hansen et al. 1990; Hansen 2000).

Global radiation, air mean temperature and precipitation for $2xCO_2$ climate were generated by general circulation model CCCM (Lapin et al. 2001). Meteorological data for reference period of years representing Danubian Lowland came from climatic station Hurbanovo (47°52’ N, 18°12‘ E). Crop yields were simulated for the reference period of years 1966–1990 in variants for emission scenarios SRES A2 and B2.

Crop parameters were set up according to the experimental data from field trials of Research Institute of Irrigation located in Most near Bratislava during years 1981–1987. Confirmation of the model was based on the results from experimental plots in Lehnice farm as well as on the data from Stationary Field Experiment of Research Institute of Irrigation from the years 1990–1994 (Takáč & Košč 1995). Rainfed and irrigated variants were evaluated.

DAISY model calculates photosynthesis rate using a light saturation response curve. The effect of CO_2 concentration was included to the DAISY parameterization according to light saturated photosynthesis rate *Fm* [g $CO_2.m^{-2}.h^{-1}$] and initial light use efficiency ϵ [(g $CO_2.m^{-2}.h^{-1}$)/($W.m^{-2}$)]. Efficiency of photo synthetically active radiation for winter wheat, and spring barley, maize and sugar beet was recalculated in dependence upon CO_2 concentration in the atmosphere (Cure & Ackock 1986) for emission scenarios SRES A2 and SRES B2 (IPCC 2001). Gradual increase of CO_2 concentration was taken into account.

Based on the statistical analyses of soil hydrophysical properties (Nováková 1996) medium textured chernozem soil profile with 3.5 % humus content in topsoil was considered as representative for the Danubian Lowland. Horizons of soil profile were defined according to texture, bulk density, parameters of retention curves, hydraulic conductivity, humus content and C/N ratio. Rooting depth was not limited by the soil.

Crop rotations of six crops (spring barley, winter wheat, maize, sugar beet, alfalfa, potato) were set up. The water regime was simulated in 2 variants: rainfed and water limited irrigation. Irrigation was applied automatically after decreasing of soil water content below 50% of AWC for each evaluated crop. Irrigation amount 30 mm was simulated. Interval between irrigations was set up to 10 days. This restriction assumption was chosen because limited irrigation water supply is expected.

Results and disscussion

Water balance of soil profile is significantly influenced by evapotranspiration. Reference crop evapotranspiration (*ET_0*) in reference period of years 1966–1990 was 819 mm. Shortage of available water especially during growing season caused that actual evapotranspiration (*ET*) was only 481 mm. *ET_0* would increase by about 7 % according to SRES B2 (879 mm) and by 12% to SRES A2 (918 mm). Crop specific potential evapotranspiration (*ET_c)* up to time horizon 2071–2100 will increase by 5% (SRES B2) or 10% (SRES A2) as compared with reference period of years. Relatively higher increase in *ET_c* values is supposed for summer time crops (e.g. maize) as compared with wintering crops or crops of the spring growing season. Annual *ET* will increase consequently towards more distanced time horizons according to SRES B2 only. According to SRES A2 increase of *ET* is supposed only in near future because shortage of water in soil profile in far future will reduce evapotranspiration (Table 1).

Taking into account only the period from sowing to harvest more significant increase of *ET_c* can be expected for the summer crops. *ET* will rapidly grow in the initial period and then gradually decline or stabilize (Table 2). Rise of the evaporation requirements will lead to increased water scarcity in the spring and summer, despite increasing precipitation totals (Fig 1).

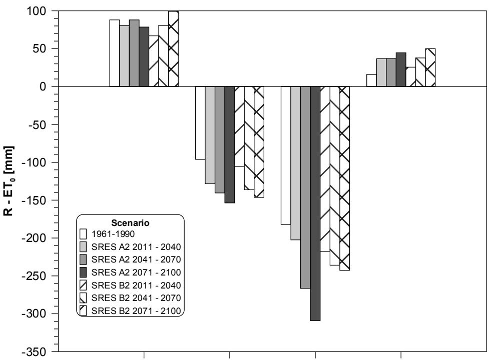


Figure 1. Seasonal climate water balance in the period 1961–1990 and according to the climate change scenarios.

Soil moisture is one of the most variable soil properties. Soil moisture regime is seasonally influenced on lowlands of Slovakia. The maximum soil water content is recorded in dependence upon winter rains or date of snow melting at the end of winter period or at the beginning of spring and the minimum soil water content is recorded during summer months. Median values (every second year) of SWC bellow 50 % of AWC lasted according to model simulations since June till the end of September. If the upper quartile (3 from 4 years) values are considered the water content bellow 50 % of AWC is recorded since the beginning of July until the second decade of September.

Simulations with climate change scenarios data increase variability of water content regime during year. Generally the decline of soil water content during growing seasons especially in summer months (since May till September) confirm decreases of all evaluated statistical characters, upper and lower quartiles, medians and averages (Fig 2). Simulations according to SRES A2 show that the upper quartile of the water content in soil layer 0–100 cm will be deeply below 50 % of AWC since half of June till half of September up to horizon of years 2071–2100. On the other hand in some years the SWC below 50 % of AWC are not calculated.

Table 1 Mean annual totals of reference crop evapotranspiration ET_0, crop specific potential evapotranspiration ET_c and actual evapotranspiration ET in the period 1966 – 1990 and according to the climate change scenarios

Scenario	Period	ET_0	ET_c	ET
	1966 – 1990	819	892	481
SRES A2	2011 - 2040	852	915	542
	2041 - 2070	881	942	514
	2071 - 2100	918	978	502
SRES B2	2011 - 2040	851	915	521
	2041 - 2070	860	921	530
	2071 - 2100	879	937	546

Number of days with SWC below 50 % of AWC will rise in conditions of climate change (Fig 3). Continual period of days when SWC is below 50 % of AWC will rise too. The extreme period of drought according to this parameter was simulated according to SRES A2 with duration since the end of May till half of December. The most frequent decrease of SWC bellow 50 % of AWC – 20 days in average is prognosed for July and August. According to SRES A2 this decrease could be expected during whole July and August at later time horizons. This trend of increasing of drought periods has been observed even during recent years. Comparing results of simulations for years 1966–1985 and 1986–2005 there were recorded in average four days more with SWC below 50 % of AWC towards later period on Danubian Lowland. The same trend was found for duration of the continual drought when increase up to 12 days was calculated.

On the other hand rising concentration of CO_2 in the atmosphere can positively influence water use efficiency (*WUE)* especially for C3 crops while C4 crops would not be influenced significantly (Fig 4).

Table 2 Crop specific potential evapotranspiration ET_c and actual evapotranspiration from sowing to harvest in the period 1966–1990 and according to the climate change scenarios

Scenario	Period	Winter Wheat		Spring Barley		Maize	
		ET_c	ET	ET_c	ET	ET_c	ET
	1966–1990	548	412	427	270	649	396
SRES A2	2011–2040	561	472	439	319	666	429
	2041–2070	568	424	436	293	687	389
	2071–2100	589	427	458	294	721	356
SRES B2	2011–2040	558	437	435	304	668	403
	2041–2070	561	421	434	291	672	401
	2071–2100	569	435	439	307	683	413

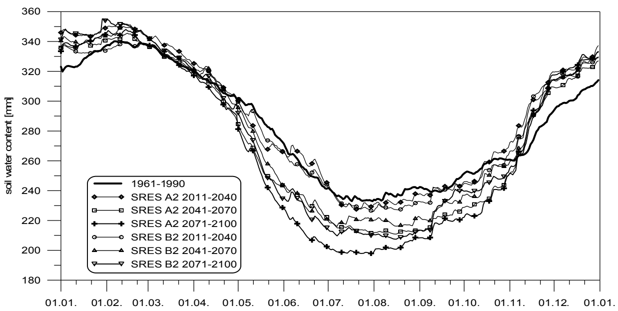


Figure 2 Annual course of mean soil water content in the horizon 0–100 cm [mm] on Danubian Lowland in the period 1961–1990 and according to the climate change scenarios.

Table 3 Earliest (e) and mean (m) date of first irrigation of selected crops in the period 1966 – 1990 and according to the climate change scenarios

Scena -rio	Perio d	Spring barley		Winter wheat		Maize		Sugar beet	
		e	m	e	m	e	m	e	M
	1966–1990	9..5.	20.5.	13. 5.	23. 5.	23. 6.	6. 7.	6. 6.	15. 6.
SRES A2	2011–2040	27. 4.	10. 5.	17. 4.	6. 5.	7. 6.	25. 6.	19. 5.	9. 6.
	2041–2070	21. 4.	6. 5.	11. 4.	2. 5.	28. 5.	14. 6.	7. 5.	28. 5.
	2071–2100	20. 4.	5. 5.	8. 4.	2. 5.	30. 5.	9. 6.	30. 4.	21. 5.
SRES B2	2011–2040	28. 4.	11. 5.	19. 4.	5. 5.	16. 5.	22. 6.	16. 5.	8. 6.
	2041–2070	26. 4.	13. 5.	21. 4.	10. 5.	30. 5.	16. 6.	6. 5.	28. 5.
	2071–2100	23. 4.	7. 5.	18. 4.	6. 5.	31. 5.	13. 6.	8. 5.	27. 5.

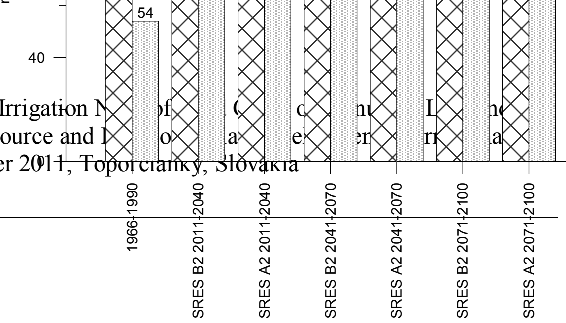


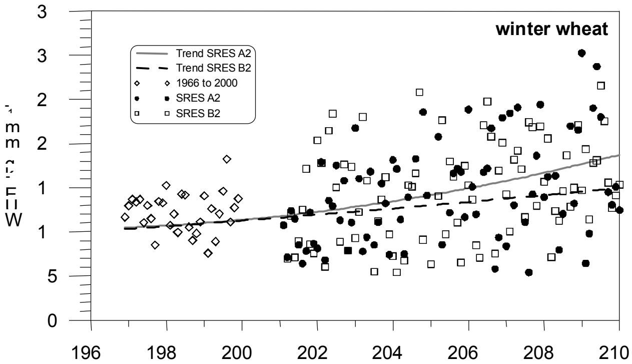
Figure 3 Mean annual number of days with soil water content below 50 % of available water capacity in the period 1961–1990 and according to the climate change scenarios.

Table 4 Mean duration of the irrigation season (days) of selected crops on Danubian Lowland in the period 1966 – 1990 and according to the climate change scenarios

Scenario	**Period**	**Spring barley**	**Winter wheat**	**Maize**	**Sugar beet**
	1966–1990	24	30	41	64
SRES A2	2011-2040	26	41	46	67
	2041-2070	30	40	60	89
	2071-2100	33	40	67	108
SRES B2	2011-2040	26	41	50	67
	2041-2070	31	41	59	88
	2071-2100	31	34	64	96

Rainfall totals and their distributions in growing season do not cover raising water demand of plant production even today. Irrigation plays important role to reach sustainable yields of field crops. Simulated irrigation requirements for different crops in reference period of years and condition of climate change are given on fig. 5. According to SRES B2 irrigation requirements of different field crops can increase by 21–105 % up to evaluated horizons of climate change and by 20 to 55 % according to SRES A2 as compared with reference period of years. The highest increase of irrigation requirements was found for sugar beet crops: 56 to105 % according to SRES B2 and 50 to155 % according to SRES A2. The increase of variability on irrigation requirements in different year was found (Fig 6).

Simulations show that time schedule of irrigation will also change during growing season of field crops. In dependence on crop, SRES and time horizon of climate change the first irrigation should be applied in average by 7–27 days earlier then in conditions of reference climate and by 11–38 days in extreme years on Danubian lowland (Table 3). Duration of irrigation season will be longer (Table 4) and water will become the most important limit of sustainable plant production.



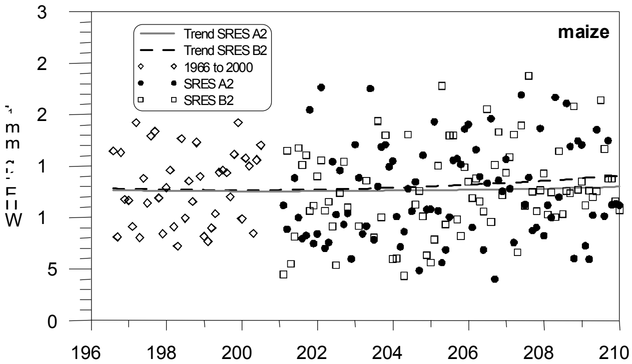


Figure 4. Winter wheat (up) and maize (down) water use efficiency WUE [$kg.mm^{-1}$] in 1966–2000 and according to the climate change scenarios.

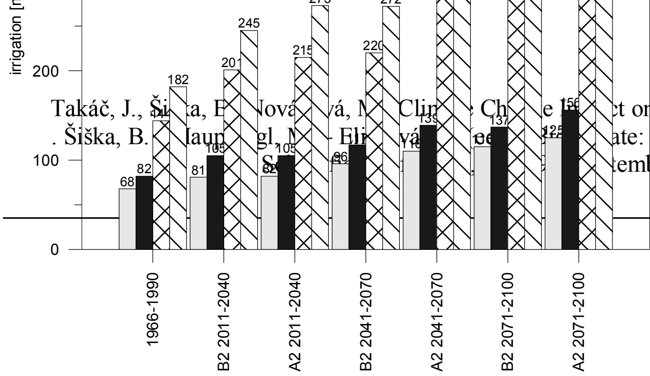


Figure 5 Average irrigation requirement [mm] of field crops in the period 1966 – 1990 and according to the climate change scenarios

Conclusions

Climate change impacts on soil water regime and irrigation requirement under different field crops growing on Danubian Lowland were evaluated by agroecological model DAISY. Meteorological data generated according GCM CGCM2 were applied according to emission scenarios SRES A2 and B2. Gradual increase of CO_2 concentration in the atmosphere was taken into account for evaluations.

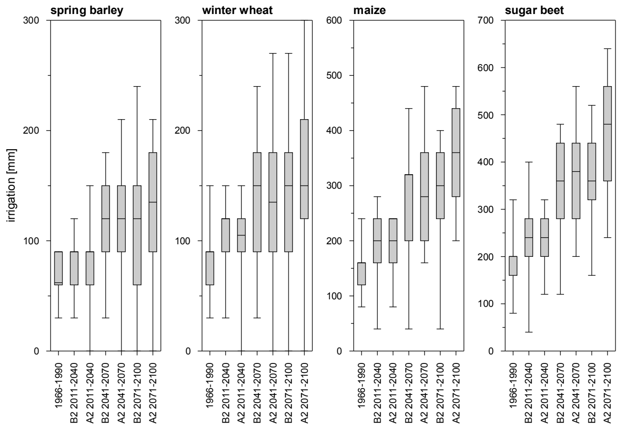


Figure 6. Statistical characteristics of irrigation requirement [mm] of field crops in the period 1966–1990 and according to the climate change scenarios.

According to both emission scenarios consequent increase of potential evapotranspiration, actual evapotranspiration and crop water requirements will increase up to time horizon from 2071 to 2100. Rising CO_2 concentration will positively influence productivity of C3 crops due to increase of water use efficiency.

As resulted from simulations of climate change impacts the shortage of soil water will deepen. Number of days with available water capacity below 50% will increase during the growing season of field crops and it will evoke increase of irrigation requirement. The irrigation season will start earlier and will persist for longer time. Insufficient water sources for irrigation could be the limiting factor of sustainable yields of field crops.

Acknowledgements: We gratefully acknowledge the support of the Grant Agency of the Slovak Republic: VEGA 1/0866/10: *Proposal of adaptive measures to reduce negative climate change impacts on agricultural landscape of Danubian lowland*

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