Assessment of climate change impact on crop water requirements in Serbia in 2030 using CROPWAT model

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Abstract. One of the main problems in facing with the effects of climate change on crops is identification of efficient and sustainable mitigation and adaptation options for selected crops and environment. In this study impact of climate change on effective rain, crop water demand and irrigation requirements is calculated using CROPWAT 8.0 software package. Projections of the future climate were taken from the ECHAM5 climate models with the SRES-A2 scenario for greenhouse gas emissions for the 2030 integration period with 1971-2000 period as a reference climatology. Expected follow-up research suppose to be related to identification of crop varieties (according to favourable crop characteristics) and appropriate soil management techniques (according to favourable crop characteristics) in order to decrease negative effects of expected climate change in Serbia.

Key words

Climate change, crop water requirement, green water, blue water, water footprints.

Introduction

From the ancient times, water was main driver of migrations, conflicts and changes in human activities. Human population is intensively growing, at the same time increasing requirements for different goods, water requirements on society level almost reaching World potentials. Since welfare of whole society and especially food security is closely related to water availability, priority has to be given to its sustainable and efficient use. In many regions of the World, agriculture is main water user especially for irrigation. Therefore, careful planning of water use by crops is of strategic importance from farm to global level.

During the last decades of XX century, effectively changing climate and follow up climate change (CC) debate, add new level of complexity and uncertainty to water - agriculture -food security triangle. In a result of numerous international projects (e.g. CLIMSAVE, CIRCE, WADI, ACCELERATES, ACQWA, PRECIRIEG, SIRRIMED, TELERIEG) and actions (COST734, COST ES1106 EURO - AGRIWAT) has risen awareness about CC impact on increasing water requirements from local to global level. In fact, under the changing climate, in many European countries, lack of fresh water is likely to force upon limits not only irrigation enlargement but also the already existing systems. From this reason, the concept of water footprints (WF) become globally recognized. The WF is defined as the quantity of water used to produce a good or a service. The WF of an agricultural product is the volume of water used during the crop growing period (Hoekstra, 2003; Hoekstra and Chapagain, 2007; Hoekstra and Chapagain, 2008). Components of WF are defined as a: green water (rain or soil moisture transpired by a crop), blue water (transpired irrigated water) and grey water (the volume of water required to dilute pollutants and to restore the quality standards of the water body). Their calculation and/or forecasting is of upmost importance for policy and decision makers on all scales and aspects of society development.

According to all global climate models (GCMs), countries in south-eastern Europe are faced with a remarkable climate change impact on crop growing conditions. In this respect, the main goal of this study is to calculate impact of expected CC on green and blue water components using GCM outputs and observed data of past climate. As a tool for calculation of crop water requirements and actual irrigation was used CROPWAT 8.0 software package for the Water Resources Development and Management Service of FAO. Meteorological data describing future climate conditions are taken from ECHAM5 climate model with the SRES-A2 scenario for greenhouse gas (GHG) emissions for 2030 integration period. GCM simulations are employed using statistical downscaling technique in form of weather generator (e.g. Dubrovsky, 1996; Dubrovsky, 1997). The Republic of Serbia (in further text Serbia) is chosen as a region of interest because of its specific meridional position in south-eastern and Central Europe and Balcan Peninsula, including regions with lowland and high mountain climate characteristics.

CC impact on green and blue water components in Serbia is quantified calculating relative change of: effective precipitation, reference evapotranspiration, potential water use by crop and actual irrigation requirements in 2030 in respect to 1971-2000 reference period.

Material and methods

Location:

Serbia is landlocked country located in the Western Balkans (southeastern Europe) and in the Pannonian Plain (a region of central Europe). It lies between latitudes 41°52' N and 46°11'N and longitudes 18°51'E and 23°01'E. Northern part of country is mostly flat terrain which belongs to Panonian Plain with Danube river dominating the region. In central parts of Serbia, the terrain consists of hills, low and medium-high mountains, interspersed with numerous rivers and its, often wide, valleys. Due to its geographical position and meridional orientation climate in Serbia varies from moderate continental at northern to continental in central part of country. Southern and southwestern parts of country are subjected to Mediterranean influences while on high mountains can be find typical mountain climate. Annual air temperature varies from 6 ^{o}C (on mountains above 1000m) to 12 ^{o}C (on some regions bellow 300 m altitude). Annual temperature variation can reach 23 ^{o}C in some eastern and northeastern regions of the country. Precipitation regime is continental and Danubian with annual amount varying from 570 mm (lowlands) to 1000 mm (high mountains).

Present and future climate data and models used
Current climate conditions for 10 locations, uniformly distributed in Serbia (Tab. 1), are considered using daily weather data (air temperature and humidity, precipitation, wind speed and sunshine duration) measured during the 1971-2000 period on main climatological stations of Hydrometeorological Service of Serbia. Assessment study

Table 1. *Geographical position and dominant soil type for selected locations in Serbia.*

Location	Longitude	Latitude	Altitude	Dominant soil type
Sombor (SOM)	19° 08 °E	45° 47 °N	88	Chernozem
Novi Sad (NOV)	19° 50 °E	45° 15 °N	80	Chernozem
Pozarevac (POZ)	20.03 °E	43.83 °N	310	Cambisol
Kraljevo (KRA)	20.70 °E	43.72 °N	215	Cambisol
Krusevac (KRU)	21.35 °E	43.57 °N	166	Fluvisol
Cuprija (CUP)	21.37 °E	43.93 °N	123	Fluvisol
Nis (NIS)	21.90 °E	43.33 °N	201	Fluvisol
Zajecar (ZAJ)	22.28 °E	44.88 °N	144	Cambisol
Dimitrovgrad (DIM)	22.75 °E	43.02 °N	450	Fluvisol
Vranje (VRA)	21.90 °E	42.48 °N	432	Fluvisol

was curried out using projections of the future climate taken from the ECHAM5 global climate model with the SRES-A2 scenario for greenhouse gas (GHG) emissions for the 2030 integration period. To synthesize daily weather data series from GCM simulations Met&Roll weather generator (Dubrovsky, 1997) was used as a tool for statistical downscaling. Weather generator is trained using 1971-2000 period as a reference climatology.

Table 2. Some crop characteristics used in simulations.

Crop	Planting date	Length of VP (days)	Crop height (m)
Maize (MZ)	15.04.	150	2.0
Potato (PT)	01.04.	145	0.6
Sugar beet (SB)	25.03.	185	0.7

Daily data of present and future climate are used as input data for CROPWAT 8.0 model. This computer program is designed for calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. All calculations in CROPWAT 8.0 are based on the two FAO publications, "Crop Evapotranspiration - Guidelines for computing crop water requirements" and "Yield response to water". Besides meteorological data, important input data for CROPWAT model are crop and soil data. Having in mind economic and strategic impact, maize, potato and sugar beet are chosen as a crops of interest. Plant characteristics used in simulations are presented in Table 2.
According to FAO soil classification (FAO/IIASA/ISRIC/ISSCAS/JRC 2009) dominant soil types on selected locations are: Chernozem (Phaozem) in Northern Serbia, Cambisol in major part of Central Serbia as well as Fluvisol and Leptosol in some smaller regions. More detailed information about soil characteristics, used in simulations, are presented in Table 3.

Table 3. *Soil characteristics of dominant soil types for selected locations in Serbia. (A - Total available soil moisture (mm/m), B - Maximum rain infiltration rate (mm/day); C - Maximum rooting depth (cm); D - Initial soil moisture depletation (%); E - Initial available soil moisture (mm/m)).*

Soil type	Plant	A	B	C	D	E
Chernozem	MZ	195	55	150	50	97.5
	PT	104	55	80	50	52.0
	SB	156	55	120	50	78.0
Cambisol	MZ	110	30	100	55	50
	PT	110	30	60	60	50
	SB	-	-	-	-	
Fluvisol	MZ	150	40	120	50	60
	PT	150	40	70	50	60
	SB	150	40	120	50	60

Reference evapotranspiration is calculated using Penman - Monteith equation while effective precipitation is calculated using USDA Soil Conservation Service Method (Dastane, 1978). The relative change of: effective precipitation, reference evapotranspiration, potential water use by crop and actual irrigation requirements in 2030 is calculated in respect to 1971-2000 as a reference period.

Results and discussion

Ten climatological weather stations were selected for the study (Table 1), with different soil types prevailing within the vicinity of the stations. One of the most important effects of expected CC on plants is exerted in changes of reference evapotranspiration. According to results presented in Table 4, tremendous changes of reference

Table 4. *Relative change of reference evapotranspiration for 2030 against 1971-2000 reference period.*

Location	δ_{ETo} (%)
CUP	67
DIM	75
KRA	52
KRU	55
NIS	54
NOV	100
POZ	39
SOM	81
VRA	83
ZAJ	77

evapotranspiration should be expected at whole territory of Serbia varying from 38.9 % (POZ) to 100 % (NOV). The relative change of effective precipitation, reference evapotranspiration, potential water use by crop and actual irrigation requirements for 2030 climate conditions are calculated for maize, potato and sugar beet crops. Obtained results are summarized in Tables 5-7. The "-" sign is related to locations where Cambisol is dominant soil type and where sugar beet cannot be grown.

Table 5. Relative change of effective precipitation (%) for 2030 against 1971-2000 reference period.

Location	Maize	Sugar beet	Potato
CUP	-18	-11	-6
DIM	-29	-24	-23
KRA	-15	-	-23
KRU	-24	-19	-9
NIS	-14	-16	-33
NOV	-20	-18	-5
POZ	-20	-	-20
SOM	-21	-19	-30
VRA	-24	-26	-22
ZAJ	-8	-	-30

In agricultural production, effective precipitation refers to portion of rainfall that can effectively be used by plants. Precipitation losses depend on soil type, slope, crop canopy, intensity of precipitation and the initial soil water content. According to applied climate projections, scarcity of effective precipitation will affect all crops. Most pronounced effects are expected in southern and south-eastern parts of country (DIM, NIS, VRA) with an decrease far above 25 %. Significant reduction of effective precipitation accompanied with more exerted increase in evapotranspiration leads to increased deficit of precipitation during the growing season of selected plants. Therefore is obtained increased potential water use by crop for all regions and analyzed crops (Tab. 5). Under such conditions actual irrigation requirements suppose to increase significantly. According to results obtained, can be expected that without irrigation, maize, sugar beet and potato will be grown under enormous drought stress conditions. It can reduce yield directly (through reduction of quantity and quality of yield) and indirectly through reduction of plant vulnerability to diseases and weeds.

Table 6. Relative change of potential water use by crop (%) for 2030 against 1971-2000 reference period.

Location	Maize	Sugar beet	Potato
CUP	37	40	38
DIM	53	54	55
KRA	26	-	29
KRU	32	34	35
NIS	27	30	29
NOV	60	63	61
POZ	26	-	29
SOM	55	57	57
VRA	55	56	56
ZAJ	49	-	52

Table 7. Relative change of actual irrigation requirements (%) for 2030 against 1971-2000 reference period.

Location	Maize	Sugar beet	Potato
CUP	117	102	89
DIM	152	134	149
KRA	111	-	126
KRU	126	111	99
NIS	60	66	85
NOV	163	153	117
POZ	146	-	145
SOM	151	138	155
VRA	112	120	116
ZAJ	99	-	127

Conclusions

Results presented in this study, are obtained using ECHAM5 climate model outputs and CROPWAT 8.0 model. Expected changes of climate in Serbia will produce increased requirements for irrigation of maize, sugar beet and potato. It will be a price of keeping actual quantity and quality of crop yield. Since amount of water available for irrigation is limited, prime goal of future crop production in Serbia is development and operational application of new and efficient agricultural management practices in order to minimize actual and forthcoming irrigation.

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