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MODELLING WINTER WHEAT SOIL WATER BALANCE IN CHANGING CLIMATIC CONDITIONS

SUMMARY

In the past decades, the climatic conditions in the region have changed, showing extreme weather events and gradual changes in precipitation and evapotranspiration. The historical climatic data (1961-1999) are calculated to average, but the extreme dry (2000) and wet (2014) years are also taken into consideration. The sediment's hydraulic conductivity is calculated using the Hydrus 1D model and measured on-site to establish the assessment model for various crops that will be easily simulated. The calculated vs. experimental values showed good agreement for the selected location of Srbovac village. Other parameters, such as soil moisture field capacity, soil moisture at the wilting point, maximum infiltration flux, and maximum drainage flux to the saturated zone, were calculated, too. Finding the adequate crop water requirement for changed soil water balance is done by using the FAO CROPWAT program. Three different soil textures were used for calculations: loam, sandy loam, and silty loam. Soil moisture at field capacity is found to be 220 mm/m, the maximum infiltration flux per day was 250 mm, and the maximum drainage flux to the saturated zone was 5 mm. The soil water balance was calculated by CROPWAT and presented for each month. In the period from 1961-1999, historical data, the total average precipitation was 911 mm, reference evapotranspiration (ETo) was 879 mm, and actual evapotranspiration (ETa) was 375 mm, but crop evapotranspiration of winter wheat (ETc-Crop) for the same period was 400 mm, that proves good climatic conditions for the selected crop. In the period from 2000-2023, the average climatic conditions were used for Crop-Water balance calculation, and the total precipitation was 712 mm, whereas ETo was 924 mm, ETa was 477 mm, and ETc-Crop of winter wheat for the same period was 641 mm, with 166 mm crop deficit in April, May, and June.

Keywords: Evapotranspiration, FAO CROPWAT 8.0, Effective Rainfall

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INTRODUCTION

Soil-water balance (SWB) represents the relationship between soil and water as its liquid phase. It is a key soil feature on ecological and economic parameters in agriculture and hydrology. This balance is determined by the entry of water into the soil, its surface runoff, the movement of water through the soil, either ascending, descending, or lateral, as well as loss from the soil, whether it is surface runoff, deep percolation, evaporation, or transpiration. Water in the soil has a decisive influence on agricultural crop growth, development, and yield. Water in the soil doesn't mean only the total water content but also presents the hydrological categories and, above all, the retention capacity and the wilting point. Between these two constants, water is available to plants, which plants can use for their growth and development. Soil-water balance depends on the quality of the soil, especially its physical properties (e.g., particle size distribution, porosity, capillarity of pores, etc.), but also on external conditions in the first raw climatic and topographic ones. Therefore, climatic changes have a high impact on SWB. Many authors have published research on this topic. Porporato and Daly (2004) present a simplified framework, analysing how hydroclimatic variability (mainly the frequency and amount of rainfall events) affects soil and plant relations in soil moisture dynamics and the impact on vegetation conditions. They have provided a general classification of the soil-water balance in global ecosystems based on two main dimensionless groups summarising climate, soil, and vegetation conditions. They concluded that fluctuations in evapotranspiration tend to increase the variance of soil moisture dynamics. Interestingly, it always reduces water losses compared to the case of constant potential evapotranspiration (PET). Ljusa *et al.* (2020) studied the perennial climatic parameters in the Mediterranean region of Bosnia and Herzegovina. They concluded that climate change is evident in B&H, which constituted the basis for this research into soil water balance and agricultural production. The predicted PET was based on an air temperature increase of 2°C and an expected decrease in precipitation by 25%. Touhami *et al.* (2015) conclude that forecasting climate change and groundwater recharge using three models is highly complex, especially in semiarid regions where recharge is reduced and associated with few yearly events. The analysed data suggest a transition from the semiarid conditions during the baseline period (1961-1990, 53% of the years with annual precipitation between 200-350 mm) to the arid condition at the end of the century (2071-2099; 62% of the years with annual precipitation <200 mm). Eitzinger *et al.* (2003) studied SWB and water stress on the winter wheat on two sites, without and with groundwater. Both agricultural sites with similar climatic conditions showed a simulated decrease in water stress, lower transpiration, and an increase in winter wheat yields under future climate scenarios. Groundwater in the rooting zone slightly increased the yield of wheat. Li *et al.* (2021) stated that the impacts of climate change on soil water balance mainly come from changes in spatial and temporal patterns of climatic variables such as rainfall and temperature. They have applied the HYDRUS-1D model to quantify the SWB components under multiple climate change scenarios and land use types. Their results show that considering the effect of climate change, the changes in precipitation variances dominated SWB variations. The availability of soil water and crop conditions are directly related and represent the key factors for agriculture sustainability. These factors are related to the crop type and its characteristics, such as root zone and plant physiology. Different crops have different demands for the quantity and dynamics of water. Water availability influences certain phases of plant growth, including growth, maturation, and development, as well as soil quality, tillage, and other agricultural techniques. The SWB also decisively affects water management and irrigation planning. The retention capacity of soil is a critical factor in water management. Soil texture, bulk density, and total and differential capacity influence water retention, migration, and supply to the plant. Retention capacity increases from sandy to silty and clayey soils. Water supply is crucial for the growth, differentiation, and yields of crops. Agro techniques, land use, crop rotation, and other measures are planned based on SWB, which is determined by precipitation, soil quality, and potential and actual evapotranspiration. This data provides information on the lack and surplus of water during the year, which is essential for crop selection and irrigation needs. Among others, the time and type of irrigation are determined based on water availability within the interval between retention capacity and wilting moisture. Climatic changes can significantly affect soil water balance, crop production, crop scheduling, and crop regionalisation. These changes are based on the altered conditions of precipitation, increased average annual temperature, and more frequent extreme events. Adapting agriculture production to the newly established soil-water-climatic conditions can prevent these issues. In a more comprehensive examination, Weng *et al.* (2008) delved into the heightened water cycle activity as a crucial element in safeguarding the photosynthetic apparatus. Knezevic *et al.* (2013) presented results of water balance simulation on winter wheat production in the area around Bijelo Polje (Montenegro) using CROPWAT and ISAREG models. These authors successfully used models to simulate soil water balance in similar agroecological conditions. The same authors (Knežević *et al.*, 2012) also studied soil-water balance with silage-maize using CROPWAT and ISAREG models. Qin *et al.* (2014) explored the interplay between natural and social facets of the water cycle, discussing four aspects of its dualistic evolution. Understanding water storage is pivotal for grasping global and local water cycles and monitoring climate and environmental shifts (Xu *et al.*, 2013). Actual evapotranspiration serves as a vital link between land surface water balance and energy balance, influencing hydrological simulations of climate change effects (Itier *et al.*, 1992; Gerla, 1992; Xu *et al.*, 2016; Blum and Gerig, 2006). Zhao *et al.* (2013) summarised the methods for estimating evapotranspiration applied in hydrological models. Buchtele and Tesar (2009) demonstrated the predominant role of transpiration within the vegetation's annual cycle. Gao *et al.* (2012) suggested that declining trends in annual precipitation and potential evapotranspiration may lead to reduced actual evapotranspiration in a given basin. The significance of estimating actual evapotranspiration has been acknowledged for some time (Rana *et al.,* 1997), with models tested in the field. Liu *et al.* (2014) evaluated how evapotranspiration and water availability changed under shifting climatic conditions in Northern

Eurasia. Dong *et al.* (2016) extensively investigated evapotranspiration estimation in water science. Gocic *et al.* (2016) conducted a long-term analysis of precipitation and the concentration of precipitation using support vector machine methods. Mupenzi *et al*. (2012) scrutinized evapotranspiration, evaporation, and seepage losses in arid and semi-arid regions to mitigate water losses. Morari and Giardini (2001) emphasized the need for better analysis of the water cycle and monthly average evapotranspiration in specific areas. Estimating evapotranspiration relies on various climatic parameters such as air temperature, vapor pressure, and humidity. Trajkovic and Kolaković (2010) analyzed the reliability of estimating reference evapotranspiration using a simplified pan-based approach that does not require data on relative humidity and wind speed, comparing the results with lysimeter measurements in the field. The term "crop water requirement" denotes the volume of water necessary to fulfill the evaporation demand of a crop. While crop evapotranspiration and crop water demand share similarities, the latter specifically pertains to the quantity of water needed for irrigation. In contrast, crop evapotranspiration refers also to the water lost during the evaporation process.

MATERIAL AND METHODS

Study site

The study was conducted in Zvečan municipality, which is located in the northern part of Kosovo. This particular part of Kosovo is specific for its geographic, social, and environmental features.

Figure 1 Location of the experimental site

The selected parcel is 0.45 ha, with the following coordinates:42.943 N, 20.843 E. Elevation is 565 m above sea level.

Soil analysis

Three samples were taken for the planned analysis of the soil of the selected location. The collection of samples for soil physical-mechanical analysis was carried out at different depths. The first sample is from a surface of 0-32 cm, the second from 32-64 cm, and the third from a depth of 64-100 cm. The samples were placed in plastic bags and taken to the laboratory, where they were prepared for analysis using standard procedures. Grain size distribution was performed using the ISSS method.

Modelling Soil-Water Balance by using CROPWAT 8.0

The term "crop water requirement" denotes the volume of water necessary to fulfill the water demand of a crop. While crop evapotranspiration and crop water demand share similarities, the latter specifically pertains to the quantity of water needed for irrigation, whereas crop evapotranspiration refers to the water lost during the evaporation process of the crop (Allen *et al.*, 1998; FAO, 2005). CROPWAT, created by FAO's Land and Water Development Division, is a software tool designed to assist decision-making processes. Specifically, CROPWAT 8.0 for Windows is a computational tool used to determine crop water requirements and irrigation needs based on input data regarding soil, climate, and crop characteristics. It enables the formulation of irrigation schedules under diverse management conditions and facilitates the water supply assessment for different cropping patterns. FAO Penman-Monteith equation (Allen *et al.*, 1998) is used in CROPWAT 8.0 to determine reference evapotranspiration (ETo). The reference evapotranspiration (ET_o) was multiplied by the crop coefficient (Kc) to obtain crop evapotranspiration (ETc), as shown below:

$$ETc = Kc \times ET_0$$

The meteorological data are taken from FAO Climate Estimation Tools for the selected location in the case of missing actual measurements for the north of Kosovo. There are historical data from 1961-1990 and the AGERA5 data for the period from 2000-2023. Three different data sets are used for calculation: dry 2000, wet 2014, and average 2019 years.

The hydraulic properties of the analysed soil were calculated by the HYDRUS program after the soil analysis concerning the particle size distribution was done. Based on the obtained experimental results, water flow was observed through loam, sandy loam, and silty loam textured soils. The program sets the parameters characteristic of all three soil textures. The cumulative flux of the given soil profile, i.e. the upper and lower boundary flow of water in the soil. Water infiltrates on the sample's surface, which conditions a positive (Pressure Head) pressure, which represents the upper boundary flow, thanks to the selected free drainage (Free Drainage), representing free drainage under the influence of gravity.

RESULTS AND DISCUSSION

SWB and crop condition are directly connected and represent the critical factors for agriculture sustainability. They are related to the crop type and its habitus, such as the root zone and plant physiology. Various crops have various demands for the quantity and dynamics of water. Water influences certain phenophases, such as growth, maturation, and fragmentation. It also influences soil quality and the type of tillage and agro-techniques. On top of that, SWM decisively affects water management and irrigation planning. Retention capacity (0.33 kPa), soil texture, specific density total, and differential capacity decisively influence water retention, water migration, and water supply to the plant. Retention capacity rises from sandy to silty to clayey soils. Water supply is crucial for crop growth, differentiation, and yields.

Based on this, agro techniques, land use, crop rotation, and other measures are planned. To determine these measures, SWB must be determined based on precipitation, soil quality, and potential and actual evapotranspiration. This way, we get data on the annual lack and surplus of water. This data is crucial for crop selection and irrigation requirements. This can significantly influence crop selection, the time and type of planting, and crop rotation. Since water is available within the interval between retention capacity and wilting moisture, it determines the time and type of irrigation.

Climatic changes can significantly affect soil water balance, crop production, crop scheduling, and crop regionalization based on changed precipitation conditions, increased average annual temperature, and, more often, extreme occasions. This can be prevented by adjusting agricultural production to the newly established soil-water-climatic conditions. Based on the obtained experimental results with the HYDRUS model, the water flow was observed through loam, sandy loam, and silty loam.

Water content in relation to time in the observed nodes/depths (N1 - 40 cm, N2 - 80cm, N3 - 120cm, N4 - 160 cm, and N5 - 200 cm) is presented in Fig. 2. The initial water content in the observed nodes is different. In the first node (40 cm), it is 0.452 cm^3/cm^3; in the second node (80 cm), it is 0.448 cm^3/cm^3; in the third node (120 cm), the initial water content is 0.446 cm^3/cm^3, in the fourth (160 cm) 0.442 $cm^3/cm^3$and in the fifth node (200 cm) 0.44 cm^3/cm^3. The water content in all nodes reaches a maximum value of 0.45 cm^3/cm^3 (saturated water content) for similar time intervals.

The saturated water content for the loam texture is 0.43, sandy loam is 0.41, and silty loam is 0.45. The average saturated water content for the examined profile coincides with the fractions of three materials in the investigated sample, as shown in Fig. 3. The further calculation by HYDRUS 1D presented the values for Soil moisture at field capacity 220 mm/m, maximum infiltration flux 250 mm/day, and maximum drainage flux to saturated zone 5 mm/day, as seen in Fig. 4.

The cumulative flux of the given soil profile, i.e. the upper and lower boundary flow of water in the soil, are shown in Figure 4. Water infiltrates on the surface of the sample, which conditions a positive (Pressure Head) pressure, which represents the upper boundary flow (green), and maximum drainage flux (red), representing free drainage under the influence of gravity. The graph shows that the inflow and outflow of water are equal after 22 hours (the upper and lower limit flow lines are then parallel), which makes the soil stable about the water. The following input parameters for winter wheat are used for simulations (Table 1), and the following soil hydraulic properties are calculated by the HYDRUS model (Table 2).

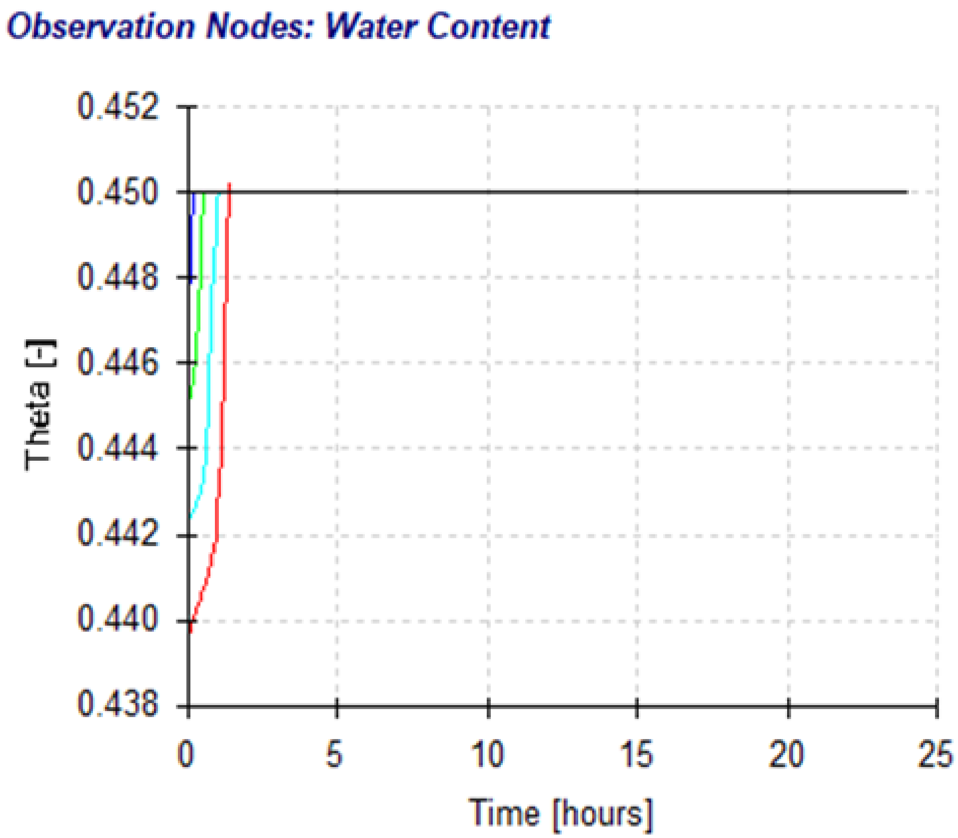

Figure 2. Soil water content (Theta) by depths vs time

Table 1. Crop data

Crop	Winter_wheat
Planting/Sowing Date	Nov-01
Depletion factor	0.55
Rooting depth [m]	0.7
Crop factor (outside growing season)	0.5
Depletion factor (outside growing season)	0.5
Rooting depth (outside growing season)	0.5

Table 2. Calculated soil hydraulic properties

Soil	sandy_loam
Soil moisture at field capacity [mm/m]	220
Soil moisture at wilting point [mm/m]	80
Maximum infiltration flux [mm/day]	250
Maximum drainage flux to saturated zone [mm/day]	5

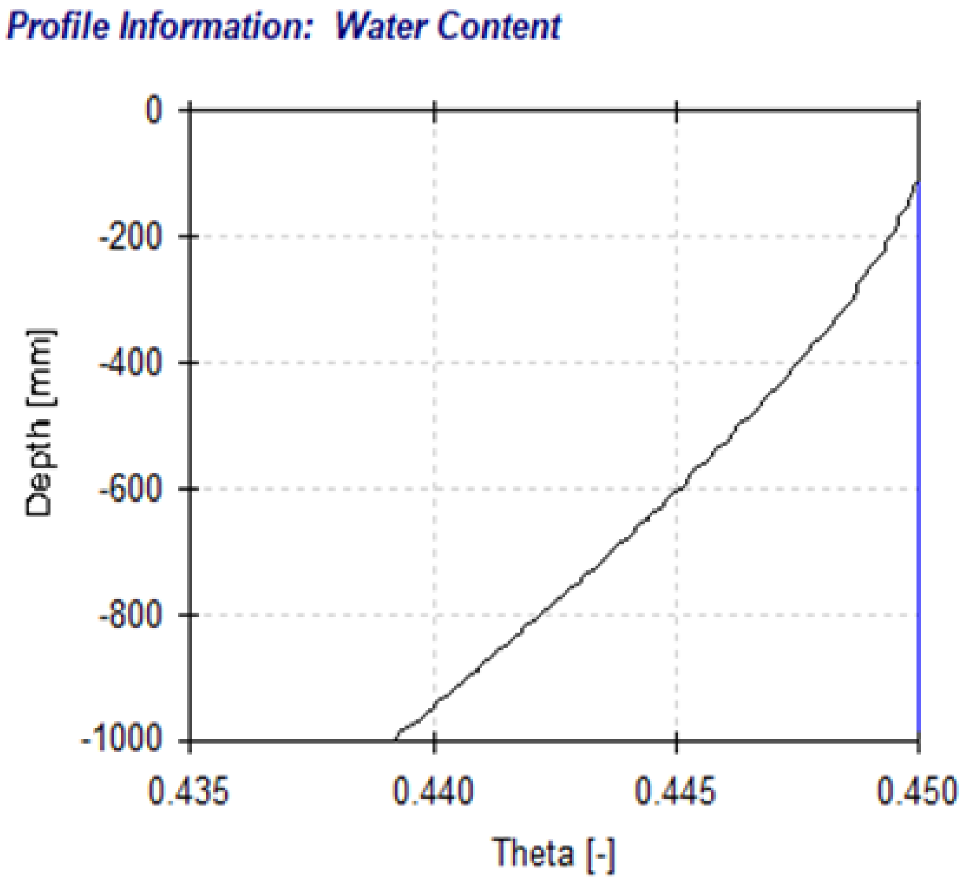

Fig. 3 Profile information - Depth vs Water Content

Table 3 presents the results of the soil water balance and crop response to water for the historical average 1961-1999.

The same crop and soil data are used to calculate the soil water balance for the average climatic conditions from 2000 to 2023. The results are presented in Table 4.

The ratio between precipitation and effective precipitation is presented in the Fig. 5.

The trends in changing climatic conditions are presented in Figure 6. In the period from 1961-1999, historical data, the total precipitation was 911 mm, and the reference evapotranspiration (ETo) was 879 mm, actual evapotranspiration (ETa) was 375 mm, but Crop Evapotranspiration of winter wheat (ETc-Crop) for the same historical period was 400 mm, that proves good climatic conditions for the selected crop. In the period from 2000-2023, the average climatic conditions were used for Crop-Water balance calculation, and the total precipitation was 712 mm, reference Evapotranspiration was 924 mm, actual evapotranspiration was 477 mm, and Crop Evapotranspiration of winter wheat for the same period was 641 mm.

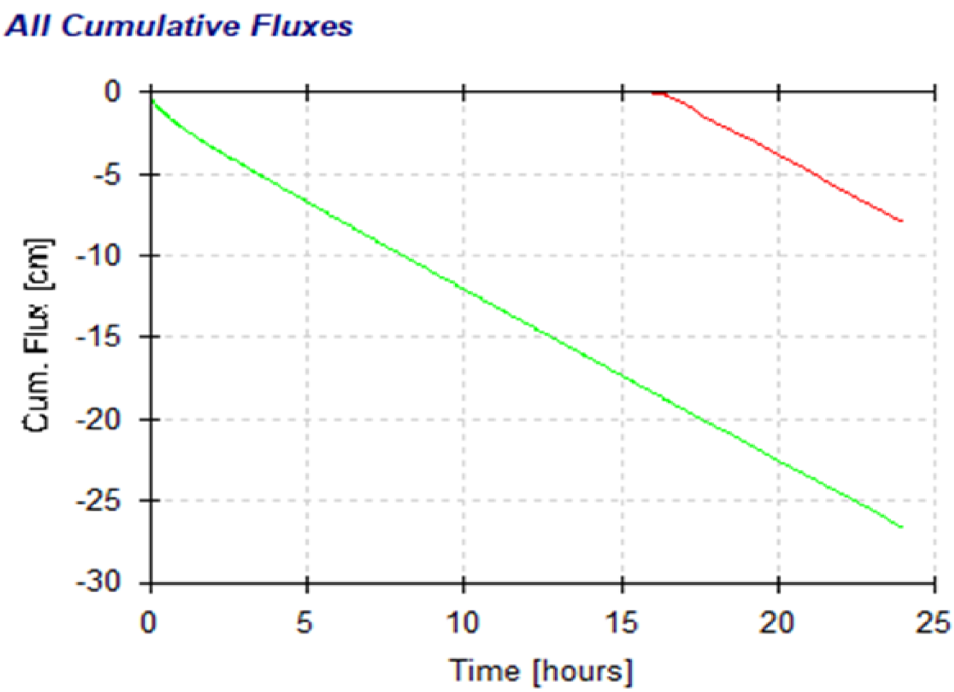

Fig. 4. Boundary Water Fluxes and Pressure Heads vs Time

Table 3. Soil water balance and crop response to water for the historical average (1961–1999)

Month	Prc.	Wet	ETo	Crop	ETcCrop	ETa	CropDef	Drain	Soil Water
	mm/m	days	mm/m	days	mm/m	mm/m	mm/m	mm/m	mm
Jan	79	15	18	31	13	13	0	0	226
Feb	69	13	27	28	23	23	0	0	225
Mar	67	9	52	31	52	52	0	0	200
Apr	113	15	78	30	88	88	0	0	193
May	56	6	106	31	122	102	20	0	135
Jun	57	8	123	28	75	70	5	0	120
Jul	73	7	145	0	0	0	0	0	0
Aug	109	16	132	0	0	0	0	0	0
Sep	93	13	91	0	0	0	0	0	0
Oct	51	10	57	0	0	0	0	0	0
Nov	76	14	31	30	16	16	0	0	220
Dec	69	15	19	31	11	11	0	0	219
Total	911	141	879	240	400	375	20	0	

Where: Prc – Precipitation in mm/month; ETo – reference crop evapotranspiration; ETcCrop - evapotranspiration under standard conditions; ETa – crop evapotranspiration under non-standard conditions; CropDef – Crop water deficit; Drain – Drainage loss; Soil Water – Soil water content in a root zone.

Table 4. Soil water balance and crop response to water (2000-2023)

Month	Prc.	Wet Days	ETo	Crop Days	ETc-Crop	ETa	Crop Deficit	Drain	Soil Water
	mm/m	days	mm/d	days	mm/m	mm/m	mm/m	mm/m	mm
Jan	24	11	15	31	51	51	0	0	157
Feb	75	25	31	28	67	67	0	0	160
Mar	107	29	68	31	98	98	0	0	168
Apr	96	27	84	30	148	136	12	0	116
May	62	23	98	31	164	69	95	0	108
Jun	22	14	131	28	86	29	59	0	100
Jul	33	18	143	0	0	0	0	0	0
Aug	17	8	145	0	0	0	0	0	0
Sep	68	24	96	0	0	0	0	0	0
Oct	72	24	62	0	0	0	0	0	0
Nov	92	27	31	30	7	7	0	0	231
Dec	43	25	19	31	20	20	0	0	201
Total	712	255	924	240	641	477	164	0	

Where: Prc – Precipitation in mm/month; ETo – reference crop evapotranspiration; ETc – Crop evapotranspiration under standard conditions; ETa – crop evapotranspiration under non-standard conditions; CropDef – Crop water deficit; GW – Groundwater recharge; Soil Water – Soil water content in a root zone.

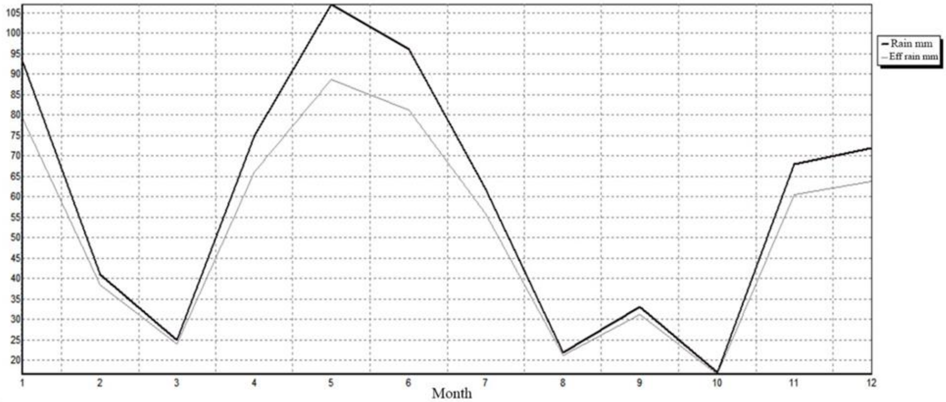

Fig.5. Rain (bold line)/Effective rain (dashed line)

Based on the presented figure, it is visible that the content of soil water in the soil profile decreased in the first decades of the 21st century. For the particular crop (winter wheat), the decrease affects the crop, especially in May and June. In June, the crop is in the phase of maturation, and the critical month is May. In the early phenophases of winter wheat lack of soil water is not affecting the crop significantly.

Čadro *et al.* (2023) stated that for the conditions of Bosnia and Herzegovina and Croatia, the key characteristic of the 1991-2020 period compared to 1961-1990 is the greater variation of all components of the water balance.

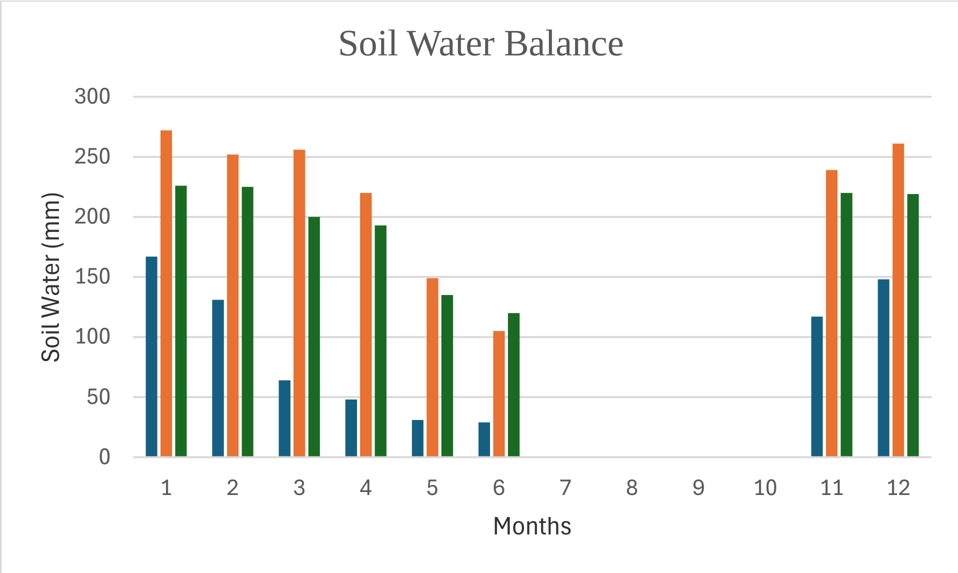

Fig. 6. Difference in Soil/Water Balance: Dry 2000(blue), Average AGERA 5 (red), Historical (green)

The obtained results can be compared with the other authors' results obtained in similar climatic conditions. Knezevic *et al.* (2013) studied Soil-water balance in the area of Bijelo Polje, Montenegro. The results show that ETa ranges from 345.5–463.3 mm. ETc ranges from 539.3–598.6 mm. Our results for winter wheat are in the range of Knezevic *et al.* (2013). The ratio ETa/ETc for the historical average is 93.8%, whereas for the AGERA5 average dataset amounts to 74.4%. In conditions of Montenegro, a 70–80% reduction in ETa resulted in a 70–80% reduction in winter wheat yield. Therefore, our results indicate that the changes in soil water balance are going to cause a reduction of more than 20% in winter wheat yield. Winter wheat is not a cash crop, and this yield decrease cannot be fixed with irrigation because the investment can hardly be paid. The extreme dry year in the period 2000-2023 was 2000, with a water deficit of 293 mm in April, May, and June. In 2000, Eta was 328mm, ETc was 684 mm. The ratio Eta/ETc was 0.48. Based on this research, the irrigation of winter wheat is not required in average conditions, but in the case of drought, as reported in 2000, irrigation is necessary.

CONCLUSIONS

The study shows that there is a change in SWB as a consequence of changed climatic conditions. Comparing the historical data (1961-1999) with recent climatic parameters (2000-2023), it can be concluded that there is a significant change in soil-water balance. This change is mainly expressed during the spring and summer months. Since winter wheat decreases its need for water by June, it suffers less than crops whose key phenophases are ongoing during summer. The obtained data show the shift in climatic conditions in the last four decades, the average climatic conditions have changed, showing higher values of Actual Evapotranspiration and Crop Evapotranspiration in the period 2000-2023. The extreme dry year in the period 2000-2023 was 2000, with a water deficit of 293 mm in April, May, and June. Based on this research, the irrigation of winter wheat is not required in average conditions, but in the case of drought, as reported for 2000, the cost-benefit analysis has to be carried out to see whether the irrigation is feasible. Further investigations will reveal the details of the climate change effects on the Soil/water balance in the region.

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