NEAR AND FAR FUTURE HYDRO-THERMAL TENDENCIES FOR CROP GROWING IN BULGARIA

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ABSTRACT

The tendencies of near and far future hydro-thermal conditions having an impact on the agroecosystems in Bulgaria are studied. Output of meteorological data from ALLADIN and ARPEGE climate models are used for estimation of near future (2020-2050) and far future (2050-2070) De Martonne aridity index, Selyaninov's Hydrothermal Coefficient and Thorntwaite potential evapotranspiration values. The same data is used as input in CROPWAT to simulate evapotranspiration, effective rainfalls, and irrigation requirements and in WOFOST model to simulate winter wheat and sunflower productivity. The tendencies of future territorial structure of winter wheat and sunflower production are traced out. Favorable and unfavorable regions are outlined.

Keywords: Climate simulations, Hydro-thermal indices, Winter Wheat, Sunflower, Zoning, Bulgaria

1. INTRODUCTION

Climate changes and their impact are more tangible nowadays than in the near past - summer heats, giving place to sudden temperature lowering, or extreme frosts in winter, giving place to anomalous warm spells of maximum spring air temperatures; shortening of the transitional seasons – spring and autumn; drought events together with forest and field conflagrations over Europe; floods, causing considerable damages to agriculture, etc. One of the most serious problems, concerning food production is warming of climate. The historical data say that the global temperature of Europe has increased with 0.8^{o}C since mid 19th century and the last decades trends show an increase of 0.2^{o}C/10-year, particularly with 0.5^{o}C for the period 1990-2005. The climatic scenarios say the mean yearly temperature will rise with 1.4-5.8^{o}C till 2100 under emission scenario A2 and 0.9-

3.4°C under emission scenario B2. As to both scenarios, the Balkans is subjected to greater than average warming but with decrease of summer precipitation totals.

The impact of Climate Change in agriculture is explored by the simulation models, which give the perspectives for crop growth and development. The results are bases on the non-linearity of the crop-weather relationships, so that the variability of the meteorological data is concerned and the impact of climate change on agricultural production is considered and realistically assessed. The Russian models show that in 21st century the frequency of the years with 50% reduced yields will increase. Recently, every 3 of 10 years are with considerably reduced yields. This number will double till 2020, and will triple till 2070 (Alcamo et al., 2007). Hulme (1996) makes a categorization of the changes in crop production, caused by Climate Change: 1) the changed temperature and precipitation will affect the agroecological zoning, and 2) the changed soil moisture and water resources will cause changes in the duration of the vegetation period in the different parts of the world. As to Rosenzweig, Iglesias (1994) the higher temperatures will enlarge the potential vegetation period and thus the regions of agricultural production will move to the North and to higher elevations.

Agricultural drought in territory of Bulgaria endangers to turn into aridity in future and will cause a serious deficit in food production. Still, there are regions in Bulgaria, where spring and summer droughts regularly occur and occupy larger and larger territories, where summer hydrothermal conditions are often almost arid. In the different parts of the country irrigation requirements within the last decades of 20th century have increased with a half to one and a half design irrigation depth (Georgieva et al., 2006; Moteva et al., 2009ab) and the effectiveness of irrigation has increased 1.6 times (Varlev, 2008). A proof of climate warming is the 7-15 days forestall of the standard terms of the phenological stages.

Climate change puts practical issues to agricultural production process, which can be solved only if information for future possible impacts is available. Since Grieser et al. (2006) Bulgaria is situated in the moderately arid – slightly humid zone with values 20-40 of De Martonne Aridity Index (I_{DM}). In this zone, time adjusted irrigation is necessary. Considering Selyaninov Hydro-thermal Coefficient (*SHC*), which is less than 1,0 for Bulgaria, dry conditions and insufficiency of water supply is peculiar for our country (Slavov, Moteva, 2002). The 30-year (1971-2000) tendencies of I_{DM}, *SHC*, Thorntwaite *PET* and FAO Penman-Monteith reference evapotranspiration (ET_o) provide reasons to predict future warming and drought in Bulgaria (Moteva et al., 2009a, 2010)

The goal of the paper is to lay down the perspectives for the hydrothermal conditions in Bulgaria in two future periods – 2020-2050 and 2050-2070; to present near and far future zoning of winter wheat and sunflower production.

2. MATERIAL AND METHODS

The output from the climate models *ALLADIN* and *ARPEGE* for the periods 2020-2050 and 2050-2070 were used for estimation of near-future and far-future values of De Martonne Aridity Index, Selyaninov's Hydrothermal Coefficient and Thorntwaite potential evapotranspiration. Climate models' predictions were made for the emission scenario A2. Data of mean air temperature and precipitation for 48 agro-meteorological stations were processed. The base period for future assessments was 1971-2000.

De Martonne aridity index (I_{DM}) was calculated as $I_{DM} = \frac{P}{T+10}$ (De Martonne, 1925), where: P - monthly precipitation, mm; T - monthly mean air temperature, ^{o}C. Selyaninov's Hydrothermal Coefficient (*SHC*) was calculated as: $SHC = \frac{P}{0{,}1\sum T_{>10}}$ (Selyaninov, 1937), where: P and $\sum T_{>10}$ - precipitation and air temperature totals of the potential vegetation period (when T_{daily}>10^{o}C), mm and ^{o}C. Thorntwaite potential evapotranspiration (*PET*) was calculated as $PET = 1{,}6(10t/I)^{a}$ (Thorntwaite, 1948), where: *PET* - monthly potential evapotranspiration, cm; t - mean monthly temperature, ^{o}C; $I = \sum_{1}^{12} i$, i=(t/5)^{1,514} - monthly heat index, ^{o}C; a – a coefficient which varies with the heat index and is given by $a = 0{,}000000675\ I^{3} - 0{,}0000771\ I^{2} + 0{,}01792\ I + 0{,}49239$.

The output from the climatic models was used as an input in the crop productivity simulation model WOFOST to estimate future production of some agricultural crops. In this paper zoning maps for present, near-future and far-future productivity over the territory of Bulgaria of winter wheat and sunflower are presented. The evapotranspiration and irrigation requirements are simulated by CROPWAT.

3. RESULTS

The long-term average values of the indices are different for the three periods discussed. They show tendencies of worsening of the hydro-thermal conditions for crop growing in the country (Table 1). As to De Martonne's classification, the past 30-year period 1971-2000 is recognized as moist sub-humid, tending to humid, with I_{DM}=29.7 mm ^{o}C^{-1}, while the conditions in near future (2020-2050) tend to be dry sub-humid (I_{DM}=21.3 mm ^{o}C^{-1}) and in far future (2050-2070) – typically dry sub-humid (I_{DM}=16.4 mm ^{o}C^{-1}). Thornthwaite *PET* changes from 552.1 to 845.2 mm, which is an increase of 53%. Selyaninov Hydrothermal Coefficient confirms the prognosis of I_{DM}. If the water supply in the period 1971-2000 is insufficient (*SHC*=1.0), the water deficit in the period 2020-2050 will cause serious yield decrease and degradation of the phyto-eco-systems (*SHC*=0.5), and desertification is expected in the period 2070-2100 (*SHC*=0.4).

Table 1. Past, near future and far future mean values of the indices.

Indices	1971-2000	2020-2050	2050-2070
I_{DM}, mm $^{o}C^{-1}$	29.7	21.3	16.4
Thorthwaite *PET*, mm	552.1	711.9	845.2
SHC, mm $^{o}C^{-1}$	1.0	0.5	0.4

The monthly standard values of I_{DM} vary in the range of 15.8 to 44.5 mm $^{o}C^{-1}$ for the period 1971-2000, 9.0-34.1 mm $^{o}C^{-1}$ for the period 2020-2050, and 6.8 to 26.8 mm $^{o}C^{-1}$ for the period 2050-2070. They change with minus average 28.3% from the first to the second period and with minus average 34.0% from the second to the third period (totally 45.0% from the first to the third period). The greatest changes are expected for July, August and September (Fig. 1).

Monthly standard values of *PET* increase from one period to another with average 27.6% and 24.4% (totally with 47.4% from the first to the last period). For July and August monthy *PET* changes from 105.0-108.5 mm to 144.6-145.0 mm and 174.9-175.5 mm. The difference between the boundary values is equal to one application rate per month (Fig.2).

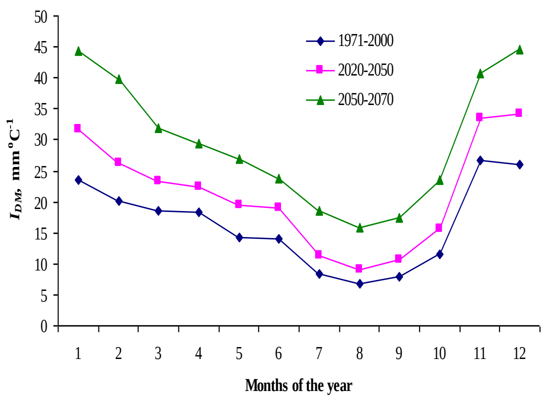


Fig. 1. Monthly dynamics of De Martonne aridity index

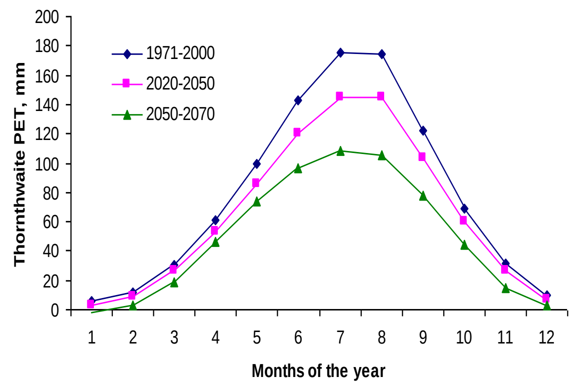


Fig. 2. Monthly dynamics of Thorthwaite Potential Evapotranspiration

The variability of I_{DM} slightly changes to stabilization. Its yearly variance coefficient of the period 1971-2000 is c_v=19.8% and decreases to c_v=18.5% and 18.1% in the next periods. c_v deviation from 1971-2000 standard is average -6.0% for 2020-2050 and -7.8% for 2050-2070 (Table 2).

Thornthwaite potential evapotranspiration varies much more within the vegetation period. It is stable for July and keeps almost the same stability for the three periods - c_v≈7.1-7.8%. The average May-September c_v changes from 11.6% to 8.1% and 8.6%. The changes of c_v with -24.3% and -19.7% and the fact that monthly *PET* increases are evidence for warming and drought processes (Table 3).

Table 2. Variance of monthly means of I_{DM} over the territory of the country and deviations according to the present climate

Months	Variance coefficient c_v, %			Deviation from 1971-2000, %	
	1971-2000	2020-2050	2070-2100	2020-2050	2070-2100
January	22.5	25.8	24.2	14.5	7.6
February	18.0	16.1	15.6	-10.4	-13.6
March	19.5	17.5	17.1	-10.6	-12.7
April	17.8	13.8	13.9	-22.5	-22.0
May	23.1	20.8	20.2	-10.2	-12.8
June	25.3	21.9	21.3	-13.3	-15.8
July	23.1	20.6	20.0	-10.9	-13.5
August	18.4	21.2	21.1	15.0	14.2
September	20.9	12.7	13.4	-39.1	-35.7
October	15.4	18.3	18.1	18.5	17.3
November	13.5	12.2	12.0	-9.7	-10.5
December	19.9	21.3	20.7	6.8	4.1
Average	*19.8*	*18.5*	*18.1*	*-6.0*	*-7.8*

Table 3. Variance of monthly means of *PET* over the territory of the country and deviations according to the present climate

Months	Variance coefficient c_v, %			Deviation from 1971-2000, %	
	1971-2000	2020-2050	2070-2100	2020-2050	2070-2100
March	48.6	13.9	13.1	-71.4	-73.1
April	17.7	9.8	9.8	-44.9	-44.9
May	10.6	8.5	9.0	-19.6	-14.9
June	8.0	9.1	9.8	12.9	21.5
July	7.2	7.1	7.8	-0.3	8.3
August	9.5	6.4	6.8	-32.9	-28.2
September	12.2	6.8	7.2	-44.4	-41.0
October	15.9	9.4	9.7	-41.1	-39.1
November	52.5	17.0	15.8	-67.6	-69.9
Average (March-November)	*20.3*	*9.8*	*9.9*	*-34.4*	*-31.2*
Average (May-September)	*11.6*	*8.1*	*8.6*	*-24.3*	*-19.7*

As to De Martonne's climate classification, the hydrothermal conditions almost all over the territory of Bulgaria in the period 1971-2000 are moist sub-humid. Only in the southern part of Struma River Valley and some small parts of the Thracian Valley and Eastern Dobrudja the conditions are dry sub-humid (Fig. 3). In the period 2020-2050 the conditions in the Eastern part of Bulgaria – Dobrudja, North and South Black Sea Regions and Eastern Thracian Valley change to dry sub-humid, while in the other part of the country it remains moist sub-humid. In the period 2050-2070 the conditions all over the country are dry sub-humid, except for a small region in Central Danube River Plain.

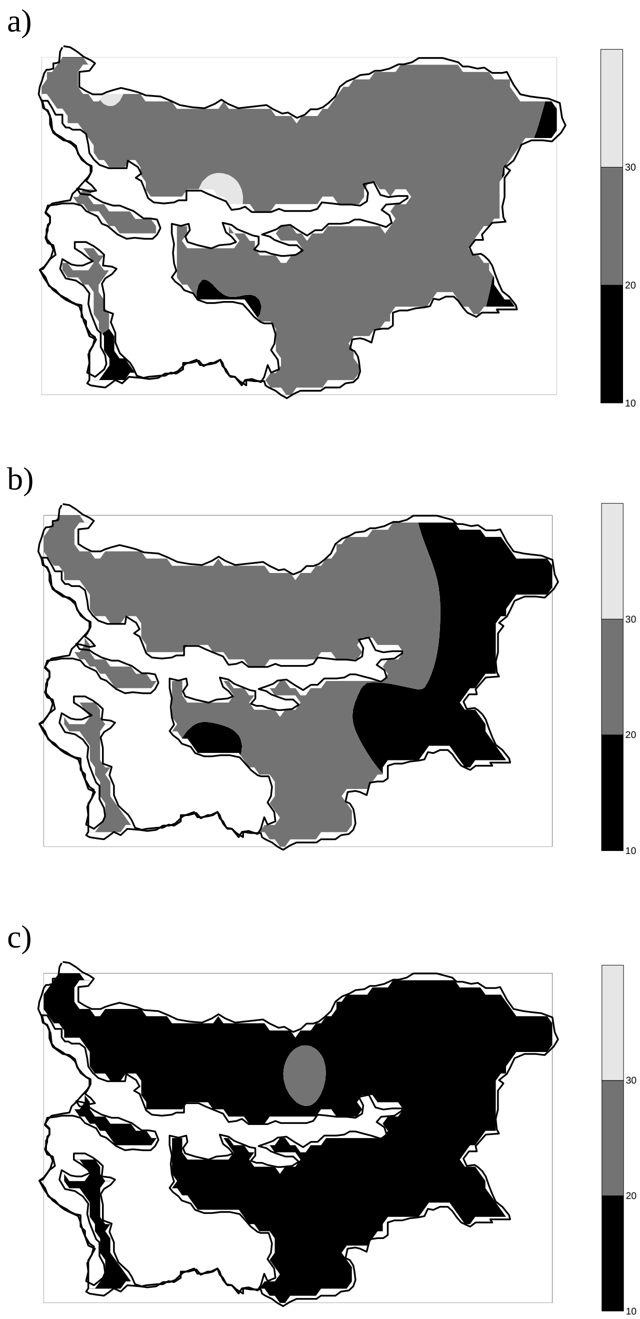


Fig. 3. Spatial distribution of De Martonne Aridity Index:
a) 1971-2000; b) 2020-2050; c) 2070-2100

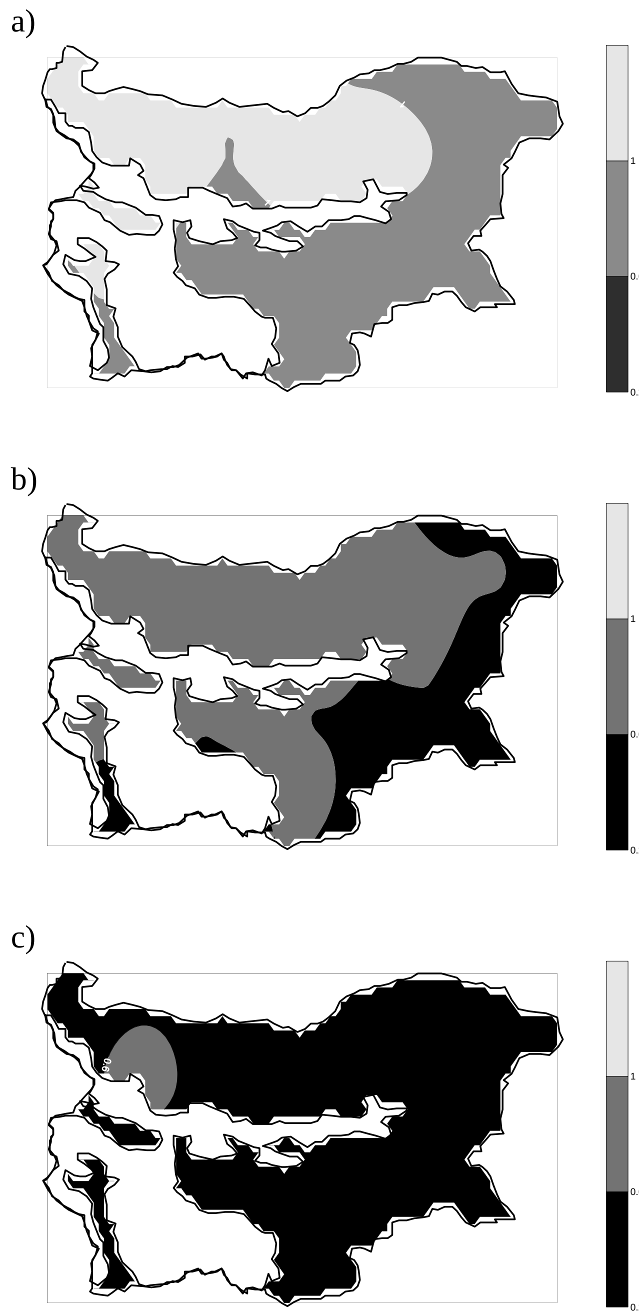


Fig. 4. Spatial distribution of Thornthwaite PET (April-October values):
a) 1971-2000; b) 2020-2050; c) 2070-2100

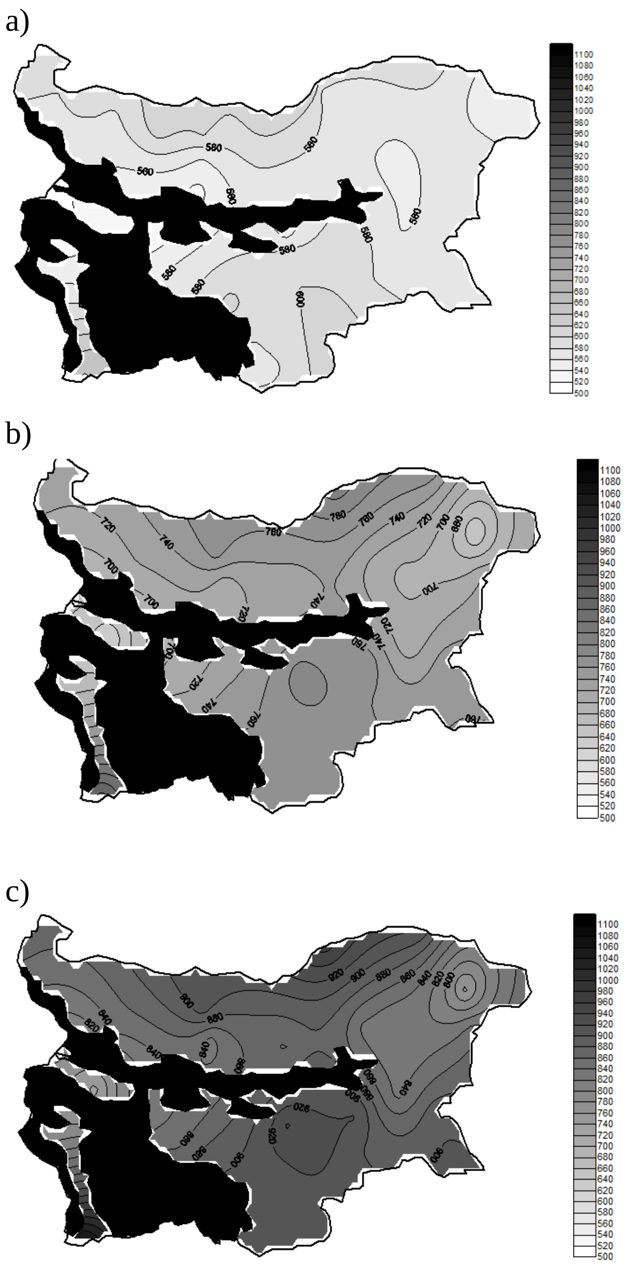


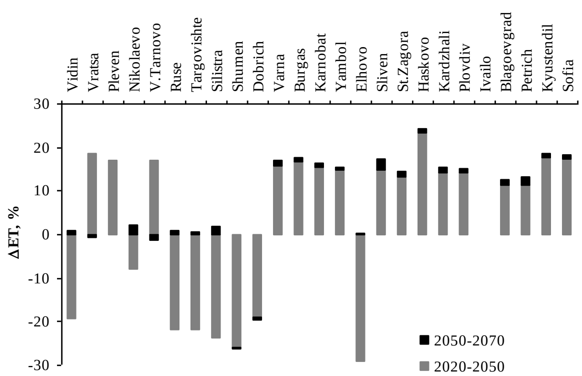
Fig. 5. Spatial distribution of Selyaninov Hydrothermal Coefficient (values of PVP (T>10^{o}C)): a) 1971-2000; b) 2020-2050; c) 2070-2100

SHC shows the same tendencies like I_{DM}. In the period 1971-2000 half of the country, mainly the Danube River Plain, has satisfactory moisture conditions. Dobrudja, Black Sea Region, Thracian Valley and Struma River Valley has insufficient water supply. In near future (2020-2050), most part of the country has insufficient water supply and North and South Black Sea Region and part of Thacian Valley have severe dry conditions with start of land degradation. Those severe conditions spread all over the agricultural areas of the country, except for some territories in Western Danube River Plain.

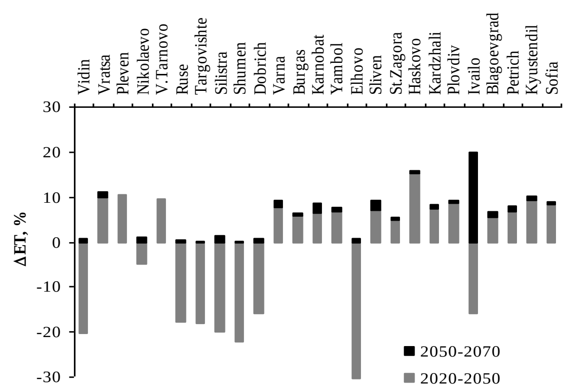
Thornthwaite PET varies from 500 to 680 mm in the period 1971-2000. The warming and drought processes in near future cause increase in the potential evapotranspiration to the range of 620-890 mm. The smallest values are found in Dobrudja and in the High Fields of Western Bulgaria. In the period 2050-2070 *PET* is highest – in the range of 730-1070. *PET* increases with nearly 100 mm per period. The conditions are worst along Struma River Valley and in the central part of Thracian Valley.

The deviations of evapotranspiration, effective rainfall and irrigation requirements of winter wheat and sunflower from 1071-2000 standards reveal greater changes for the period 2020-2050 rather than for the period 2050-2070. Evapotranspiration is greater with around 15.8% for the first period for winter wheat and still with 1.2% for the second one. The evapotranspiration of sunflower is greater with around 8.1% for the first period and with still 1.7% for the second one. There is a group of stations in Northeastern Bulgaria for which *ET* decreases with average 21.1% for winter wheat and 18.3% for sunflower (Figs 6a and 7a).

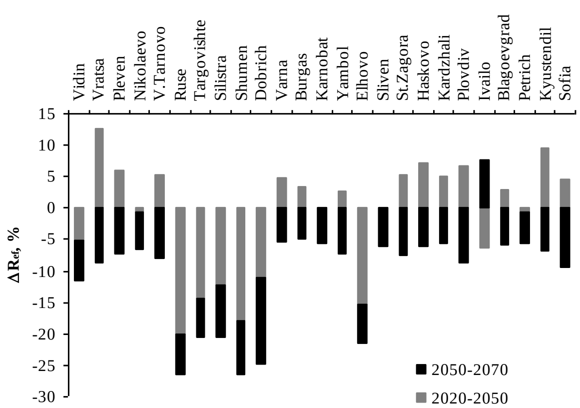
a)



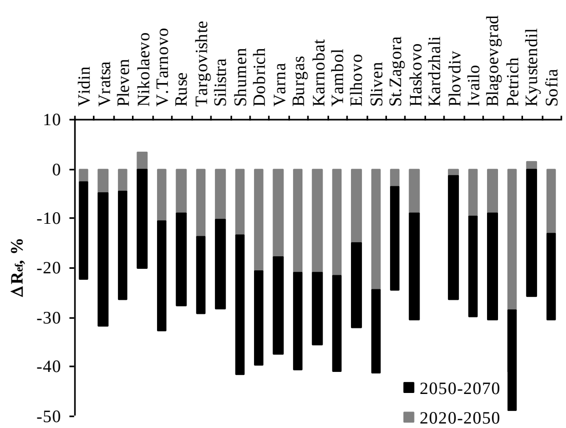
a)



b)

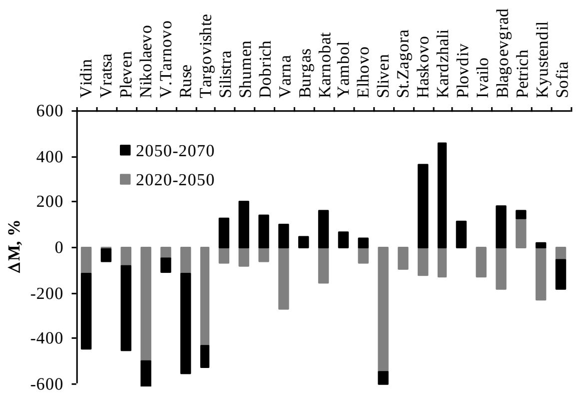


b)



c)

c)



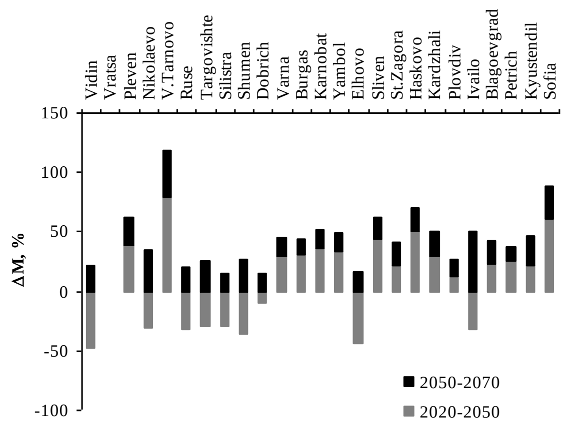


Fig. 6. Deviations of the values of actual evapotranspiration (a), effective rainfall (b) and irrigation requirements (c) of winter wheat from 1971-2000 standards

Fig. 7. Deviations of the values of actual evapotranspiration (a), effective rainfall (b) and irrigation requirements (c) of sunflower from 1971-2000 standards

Effective rainfall definitely decreases for the two periods with around 11.7% and 20.3% per period for sunflower and with 10.4% and 7.0% for winter wheat. There is a group of stations, mainly in Northeastern Bulgaria, at which the effective rainfall for winter wheat in the first period increases with around 5.1%, but for the second period it everywhere decreases (Figs 6b and 7b).

As a result, the irrigation requirements of winter wheat for the period 2020-2050 mainly decrease with 165.5% and only for one station in Southwestern Bulgaria (Petrich) it increases with 127.6%. For the period 2050-2070 they decrease with 183.5% in North Danube River Plain, but increase with average 147.4% for all the other arable land in Bulgaria. The irrigation requirements of sunflower decrease with 32.2% in the Danube River Plain for the period 2020-2050 and increase with 35.9% for the other parts of the country. For the period 2050-2070 they increase in all regions (Figs 6c and 7c).

The simulations with WOFOST model show that in the period 1971-2000 the yields of winter wheat from 50% of the territory of the country are more than 3.50 Mg/ha and in the other 50% are obtained around 2.50 Mg/ha. Only in one administrative region is obtained less than 1.50 Mg/ha. In the period 2020-2050, moisture conditions in Southeastern Bulgaria presuppose increasing of the yields and in Southwestern – decreasing them - less than 1.50 Mg/ha. In the period 2050-2070 the conditions grow severe in Northeastern and Southern Bulgaria and the yields there drop less than 1.50 Mg/ha. From the other part of the territory the yields also decrease and are in the range of 1.50-2.50 Mg/ha (Fig. 8).

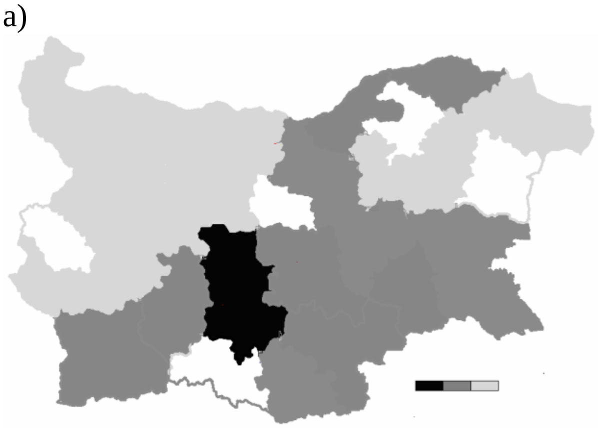
The worst conditions for sunflower growing in the period 1971-2000 are in Central Danube River Plain and in Western Thracian Valley, where the simulated yields are less than 3.00 Mg/ha. These territories complete around 25% of the arable ones. The yields from another 35% of the arable areas are between 300 and 350 Mg/ha and from 35% - greater than 3.50 Mg/ha. The conditions for sunflower growing, in analogue with those for winter wheat growing, change for better in the period 2020-2050. Both crops use the autumn-winter water reserves, which future tendency is positive. Hence the low productive territories shrink to around 15-20%, but territories with yields around 3.50 Mg/ha grow to 50-60%.Considerably high yields are expected only from 20% of the territories. The period 2050-2070 is highly unfavorable. More than 60% of the territory is risky for low yields, and 40% for medium low ones (Fig. 9).

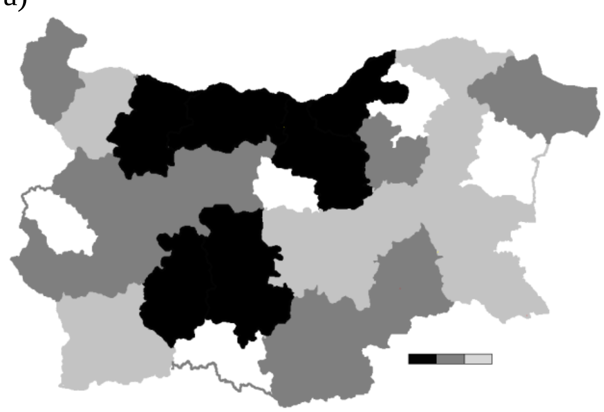
4. CONCLUSIONS

1. The long-term average values of the indices show tendencies of worsening of the hydro-thermal conditions for crop growing in the country. As to De Martonne AI present climate is moist sub-humid tending to humid, moist to dry sub-humid in near future, and typically dry sub-humid in far future.
2. Thornthwaite *PET* increases from present to far future climate with 53%.

a)

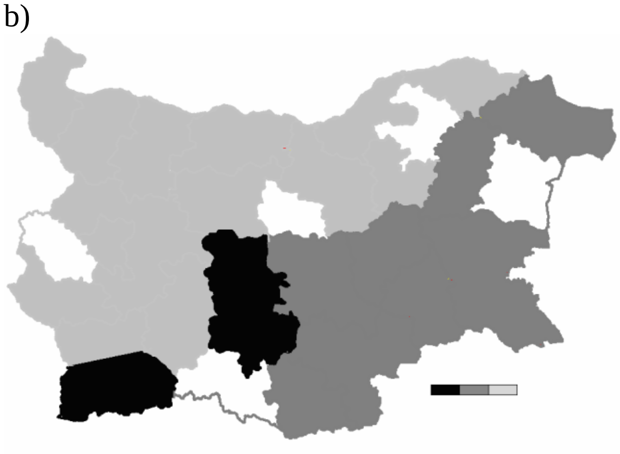
a)

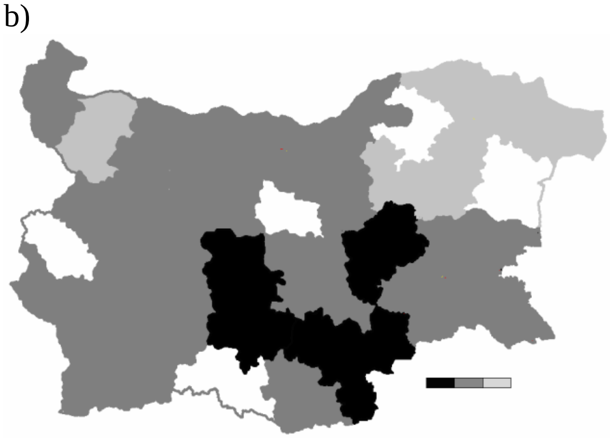




b)

b)





c)

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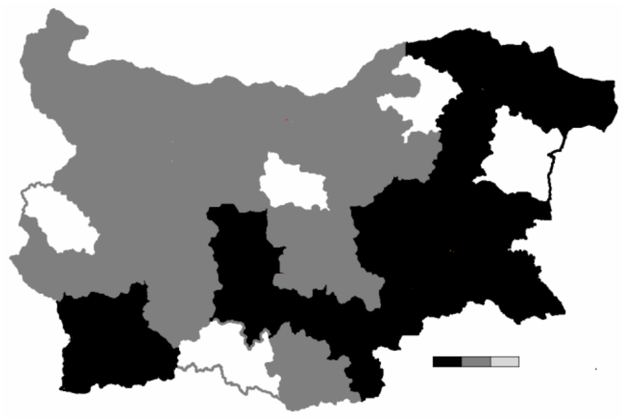

Fig. 8 Maps of the favorable and unfavorable areas for winter wheat growing:
a) 1971-2000; b) 2020-2050; c) 2070-2100

1.50-2.00-3.50 Mg/ha

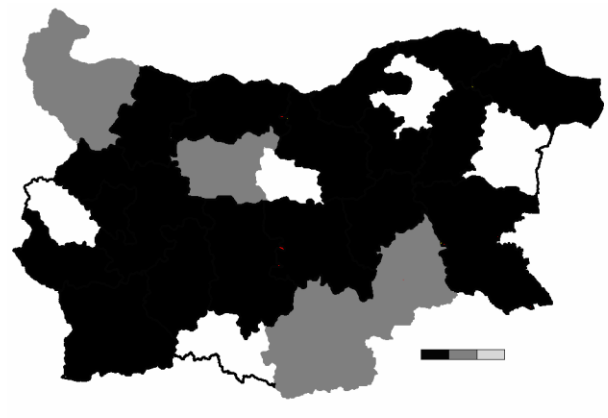

Fig. 9 Maps of the favorable and unfavorable areas for sunflower growing:
a) 1971-2000; b) 2020-2050; c) 2070-2100

3.00-3.50-4.00 Mg/ha

3. As to *SHC*, water supply changes from insufficient in the present climate to deficit in future climates, which will cause serious yield decrease and degradation of the phyto-eco-systems in near future and desertification in far future.
4. The irrigation requirements of winter wheat and sunflower mainly decrease in near future, but increase in far future
5. The yields of winter wheat and sunflower tend to increase in near future and decrease in far future.

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