CLIMATE CHANGE AND THE HYDROTHERMAL AND EVAPOTRANSPIRATION CONDITIONS IN THE PLANNING REGIONS OF BULGARIA

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ABSTRACT

Evapotranspiration of crops is the basis on which their irrigation scheduling is designed and managed. The necessary water amount, additionally given by irrigation, mainly depends on the hydrothermal conditions. They are related to the microclimatic peculiarities of the sites. Bulgaria has six Planning Regions (NUTS2 level) of different microclimatic and soil features, suitable for different crop growing.

In this paper the hydro-thermal and evapotranspiration conditions of the six planning districts of Bulgaria have been characterized and compared. De Martonne hydrothermal index and FAO Penman-Monteith reference evapotranspiration have been calculated and generalized per planning districts. Their long-term variation, tendencies and periodicity have been studied. Maps of the favorable and unfavorable for growing of autumn-winter and late spring crops have been elaborated. The long-term values of the hydrothermal indices are useful for forecasting of the agricultural production conditions of the districts and as grounds for adaptation of the agricultural practices in these districts to Climate Change. In most of the cases, the relation between the hydro-thermal indices and the yields is linear, which facilitates yield prognosis.

Keywords: Hydrothermal indices, Reference evapotranspiration, Irrigation scheduling, Planning Regions, Bulgaria

INTRODUCTION

The water supply insurance for the agricultural crops is represented by the balance between the necessary and the actual water amounts to recharge water losses by evapotranspiration. The deficit of available water causes a disturbance in plant system functioning. This affects agro-ecosystem food production. Bulgaria is situated in the zone of insufficient, uncertain and variable water supply. Field crops need irrigation almost everywhere in Bulgaria.

The necessary water amounts, additionally given by irrigation, depend mainly on the hydrothermal conditions of the sites. Bulgaria has six Planning Regions (NUTS2 level) of different microclimatic and soil features, suitable for different crop growing (Fig. 1).

Fig. 1 The Planning Regions of Bulgaria

A simple way to assess the evaporative conditions of the Planning Regions is by De Martonne Aridity Index and FAO Penman-Monteith reference evapotranspiration.

The evaporative conditions and the irrigation water requirements in Bulgaria were firstly estimated by Dilkov [1] for winter wheat on the basis of the Balance of Atmospheric Humidification. Later on, Hershkovich [2] elaborated spatial maps with allied nomograms, in which zoning of the irrigation requirements is related to the yields. This approach made the maps worth for agricultural production forecast. Zahariev et al. [3] worked out the design irrigation scheduling of 91 crops, grown in 5 agroclimatic groups of regions of different hydrothermal conditions. Recently, Georgieva et al. [4] and Moteva et al. [5, 6, 7] have assessed on the base of long-term rows of data the impact of Climate Change on the irrigation requirements across Bulgaria. For this purpose they used the Balance of Atmospheric Humidification, the available soil water, and FAO Penman-Monteith reference evapotranspiration. They established that during the last 30 years of XXth century the irrigation requirements in the different climatic districts and regions of Bulgaria have increased with a half to one and a half design irrigation depth (= 60 mm).

Due to its simplicity, De Martonne aridity index is frequently used for assessment of crop growing hydrothermal conditions. It expresses the ratio of precipitation to temperature. Since crop evapotranspiration is hardly evaluated and evaporation is rarely observed, Paltineanu et al. [8] advises to approximate crop evapotranspiration by simple structured aridity indices like De Martonne's one. In the map of De Martonne aridity index distribution over the world (Grieser et al. [9]), Bulgaria comes in the zone under sub-humid conditions with values of 20-40 mm C^{-1}, where time adjusted irrigation is necessary.

The purpose of this paper is to characterize and compare the hydrothermal and evapotranspiration conditions of the Six Planning Regions of Bulgaria through the distribution and long-term variability of De Martonne Aridity Index and FAO Penman-Monteith reference evapotranspiration.

Because of competition for water among various consumers, this study might help hydrologists and planners make proper decisions concerning how to use scarce water resources. The goal is to help preservation of water resources by these indices assessments.

MATERIAL AND METHODS

Daily data of mean air temperature and precipitation at 48 agrometeorological stations were processed. The data were taken from the database of the National Institute of Hydrology and Meteorology, BAS (Bulgarian Academy of Sciences). They cover the period 1971-2000.

De Martonne aridity index (*DM*) was calculated by the formula (De Martonne [10]):

$$DM = \frac{P}{T + 10} \tag{1}$$

where: *P* - monthly precipitation sum [mm]; *T* - monthly mean air temperature [C].

FAO Penman-Monteith reference evapotranspiration was calculated by FAO 56 calculation procedures (Allen et al. [11]).

The long-term variation, tendencies and periodicity of the indices were studied. Zoning maps were elaborated.

Wheat evapotranspiration and yields from 4 stations on different soil types were used for establishing the relations of the studied indices with crop evapotranspiration and yields. The wheat evapotranspiration under rain-fed conditions was calculated by the water-balance method.

RESULTS

De Martonne annual aridity index is highly variable over the territory of Bulgaria - from 20.7 to 41.6 mm C^{-1} (Fig. 2). The average *DM* of Bulgaria is 30.9 mm C^{-1}. DM_{PVP} (*DM* of the potential vegetation period March-October) average is lowest (the driest conditions) in South Central Region (Thracian Valley) – 22.7 mm C^{-1}, Southwestern (Sruma River Valley) – 22.9 mm C^{-1} and Northeastern (Dobrudja) Region – 23.0 mm C^{-1} (Table 1). These parts of Bulgaria, in which the arable lands are generally situated and in which the essential crops like cereals, oil crops, fruit trees, vineyards, horticultural crops, etc. are grown, have acute-arid conditions and irrigation is needed to obtain high yields. Yearly *DM* values reach 40 mm C^{-1} (humid conditions) in parts of North Central Region - the Fore-Balkan territories - and Northwestern Region. DM_{PVP} average is greatest for Northwestern Region, hence the most humid conditions are found there.

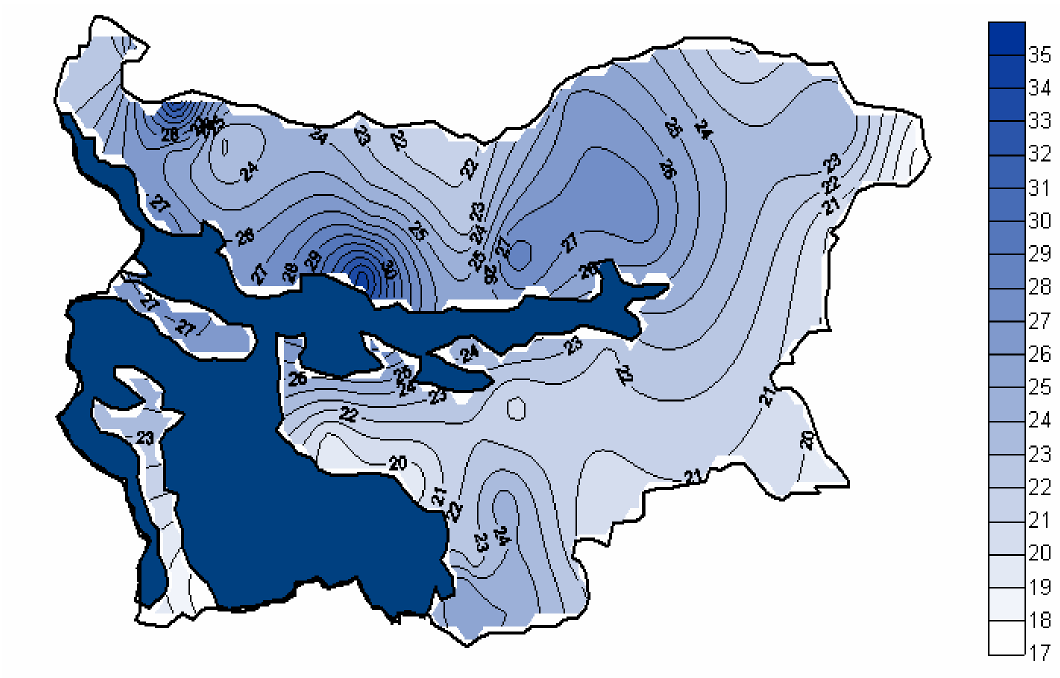

Fig. 2 Spatial distribution of De Martonne annual aridity index

Table 1 Statistical indices of the 30-year rows of De Martonne aridity index per Planning Regions and important agricultural periods

Indices/Regions	**North-western**	**North Central**	**North-eastern**	**South-western**	**South Central**	**South-eastern**
Potential vegetation period						
Average [mm C^{-1}]	25.6	24.5	23.0	22.9	22.7	23.4
StDev [mm C^{-1}]	7.7	7.6	7.6	7.4	7.3	6.3
c_v	0.30	0.31	0.33	0.32	0.32	0.27
April-June						
Average [mm C^{-1}]	30.4	27.0	25.9	25.9	26.8	27.3
StDev [mm C^{-1}]	11.6	9.8	10.9	10.7	10.1	8.7
c_v	0.38	0.36	0.42	0.43	0.38	0.32
July-August						
Average [mm C^{-1}]	19.1	22.7	16.8	16.9	16.5	15.6
StDev [mm C^{-1}]	11.0	15.8	10.8	10.5	10.7	10.2
c_v	0.58	0.70	0.64	0.66	0.65	0.65

The Planning Regions of Bulgaria have analogous comparative characteristics of the two important for agriculture in country periods – April-June - winter crops period of yield formation and July-August – the traditional late spring crops irrigational season. The lowest *DM* April-June values are observed in Southeastern and Northeastern Regions; the highest ones – in Northwestern. The extremely drought conditions are established in Southeastern and South Central Regions. The averages of July-August period are considerably lower than of April-June one. As to the classification of the dryness based on De Martonne's aridity index, the conditions in Bulgaria in April-June are moist sub-humid, and in July-August – dry sub-humid.

The variation coefficient c_v shows great moisture instability of *DM* in the summer period – variation from 58% to 70% in the different Regions, while the variation in spring is 32%-42%. c_v of *PVP* is almost the same for all Planning Regions – 27%-33% (Table 1).

The long-term variation of the DM_{PVP} shows a decreasing tendency for all the Planning Regions (Fig. 3). Analogously does *DM* for the periods April-June and July-August (Table 2). *DM* decrease indicates future warming and drought in all six Planning Regions of Bulgaria. The 5-year moving average outlines periods of favorable conditions at the beginning and at the end of the 30-year period and a period of unfavorable for agriculture hydrothermal balance during the 80s.

Table 2 30-year decrease in De Martonne aridity index trend per Planning Regions and important agricultural periods [mm C^{-1}]

Periods/Regions	**North-western**	**North Central**	**North-eastern**	**South-western**	**South Central**	**South-eastern**
Potential veg. period	9	7	6	8	9	5
April-June	14	7	4	10	13	7
Jul-August	6	15	11	13	13	11

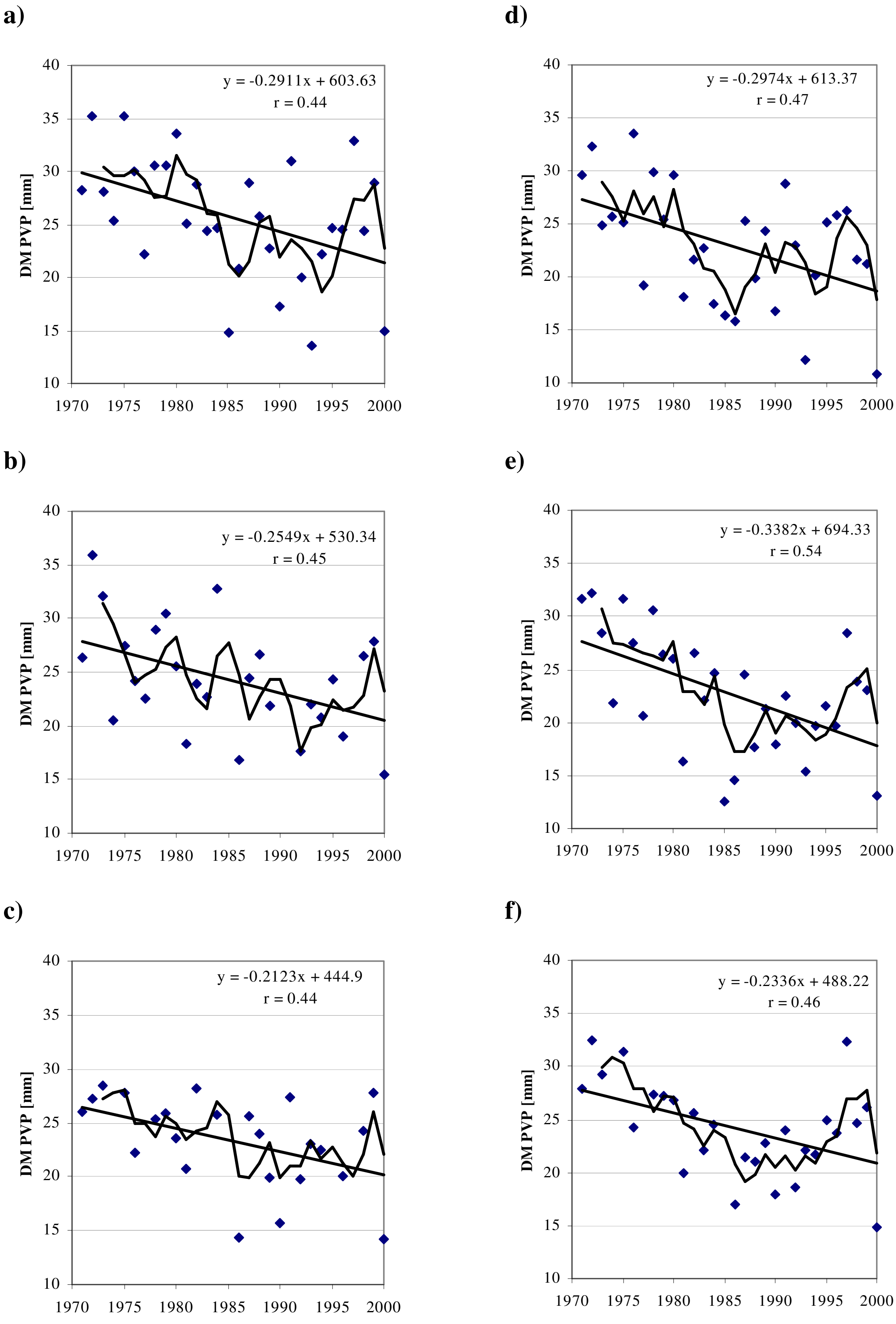

Fig. 3 Long-term tendency and 5-year moving average of De Martonne annual aridity index for the Planning Regions: a) Northwestern; b) North Central; c) Northeastern; d) Southwestern; e) South Central; f) Southeastern

DM probability shows that in 75% of the years *DM* is expected to be higher than 19.5-22.4 mm C^{-1} for *PVP*; 20.6-23.6 mm C^{-1} for April-June period and 8.4-13.2 mm C^{-1} for July-August period (Table 3).

Table 3 Values of De Martonne aridity index at a particular probability per Planning Regions and important agricultural periods [mm C^{-1}]

Probability/Regions	North-western	North Central	North-eastern	South-western	South Central	South-eastern
Potential vegetation period						
25%	30.0	28.5	27.3	26.0	27.0	27.0
50%	25.4	24.5	24.0	24.4	22.5	24.0
75%	22.4	20.6	20.0	19.5	19.7	20.7
April-June						
25%	37.4	31.9	32.1	32.0	32.5	30.3
50%	30.2	27.2	25.4	26.5	26.5	27.9
75%	23.6	21.4	20.7	20.6	21.1	23.1
July-August						
25%	28.0	33.0	22.3	21.1	21.3	22.0
50%	20.1	21.8	16.2	17.2	15.4	14.8
75%	11.2	13.2	10.0	11.7	10.7	8.4

PVP reference evapotranspiration varies over the territory of Bulgaria from 630 mm to 920 mm; for April-June period – from 225 mm to 375 mm; and for July-August period – from 225 mm to 330 mm, (Fig. 4). It is most intensive in the southern parts of Southwestern Region, also in South Central and in North Central Regions. The lowest reference evapotranspiration is observed in some pre-mountain parts of Southwestern Region.

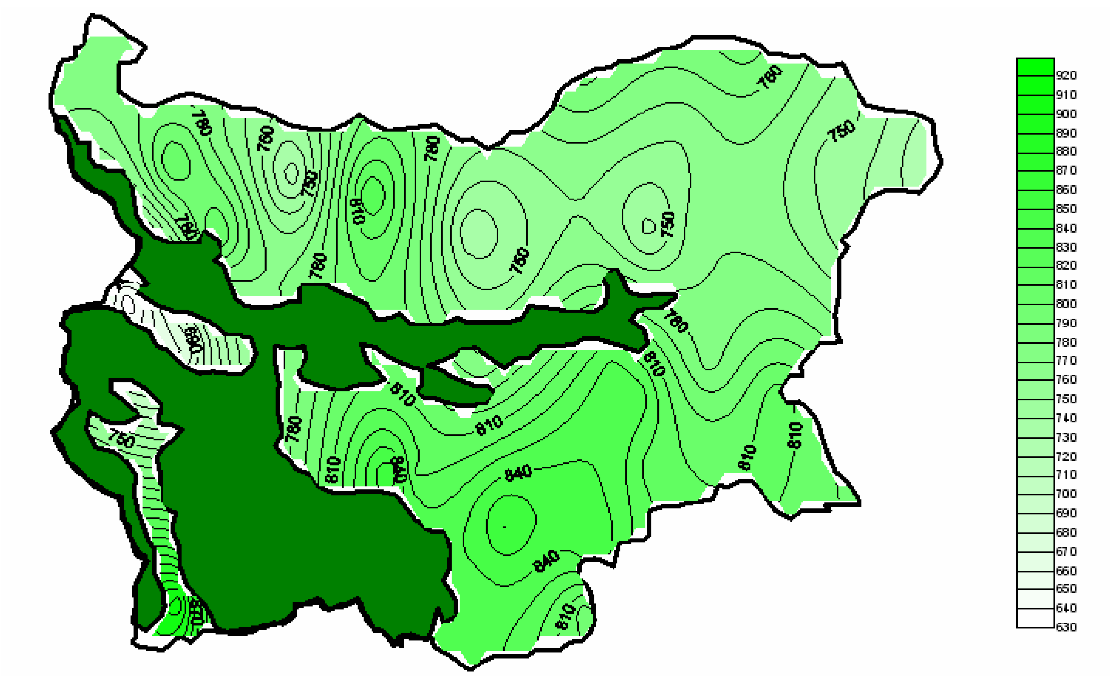

Fig. 4 March-October reference evapotranspiration over the territory of Bulgaria

The highest average $ET_{o\ PVP}$ (ET_o of the potential vegetation period) is in the South Central Region – 822.8 mm and the lowest – in the Northeastern one – 742.9 mm. Analogously April-June and July-August ET_o are highest in South Central Region – 335.7 mm and 294.6 mm respectively and lowest – in Northeastern one – 297.5 mm and 263.9 mm respectively (Table 4).

Unlike De Martonne aridity index reference evapotranspiration is stable over the territory of Bulgaria (Table 4). The variation coefficient of the three studied periods varies around 10%. The highest variation is observed in Southwestern Region, due to the presence of districts of comparatively contrast relief and microclimatic conditions.

Table 4 Statistical indices of the 30-year rows of FAO Penman-Monteith reference evapotranspiration per Planning Regions and important agricultural periods

Indices/Regions	North-western	North Central	North-eastern	South-western	South Central	South-eastern
Potential vegetation period						
Average [mm]	786.1	760.9	742.9	779.6	822.8	810.6
StDev [mm]	49.5	73.0	46.6	105.1	57.7	62.0
c_v	0.06	0.10	0.06	0.13	0.07	0.08
April-June						
Average [mm]	326.7	322.4	297.5	319.9	335.7	323.5
StDev [mm]	31.7	31.6	31.0	43.3	25.3	27.6
c_v	0.10	0.10	0.10	0.14	0.08	0.09
July-August						
Average [mm]	279.0	268.1	263.9	275.1	294.6	292.6
StDev [mm]	31.6	28.2	23.7	42.8	29.8	29.4
c_v	0.11	0.11	0.09	0.16	0.10	0.10

The 30-year tendencies of *PVP* ET_o as well as the April-June and July-August ones are increasing (Fig. 5 and Table 5). They like De Martonne aridity index indicate warming and drought processes of climate.

Table 5 30-year increase in FAO Penman-Monteith reference evapotranspiration trend per Planning Regions and important agricultural periods [mm]

Periods/Regions	North-western	North Central	North-eastern	South-western	South Central	South-eastern
Potential veg. period	120	160	90	60	100	110
April-June	45	70	30	30	30	50
Jul-August	50	60	50	40	50	60

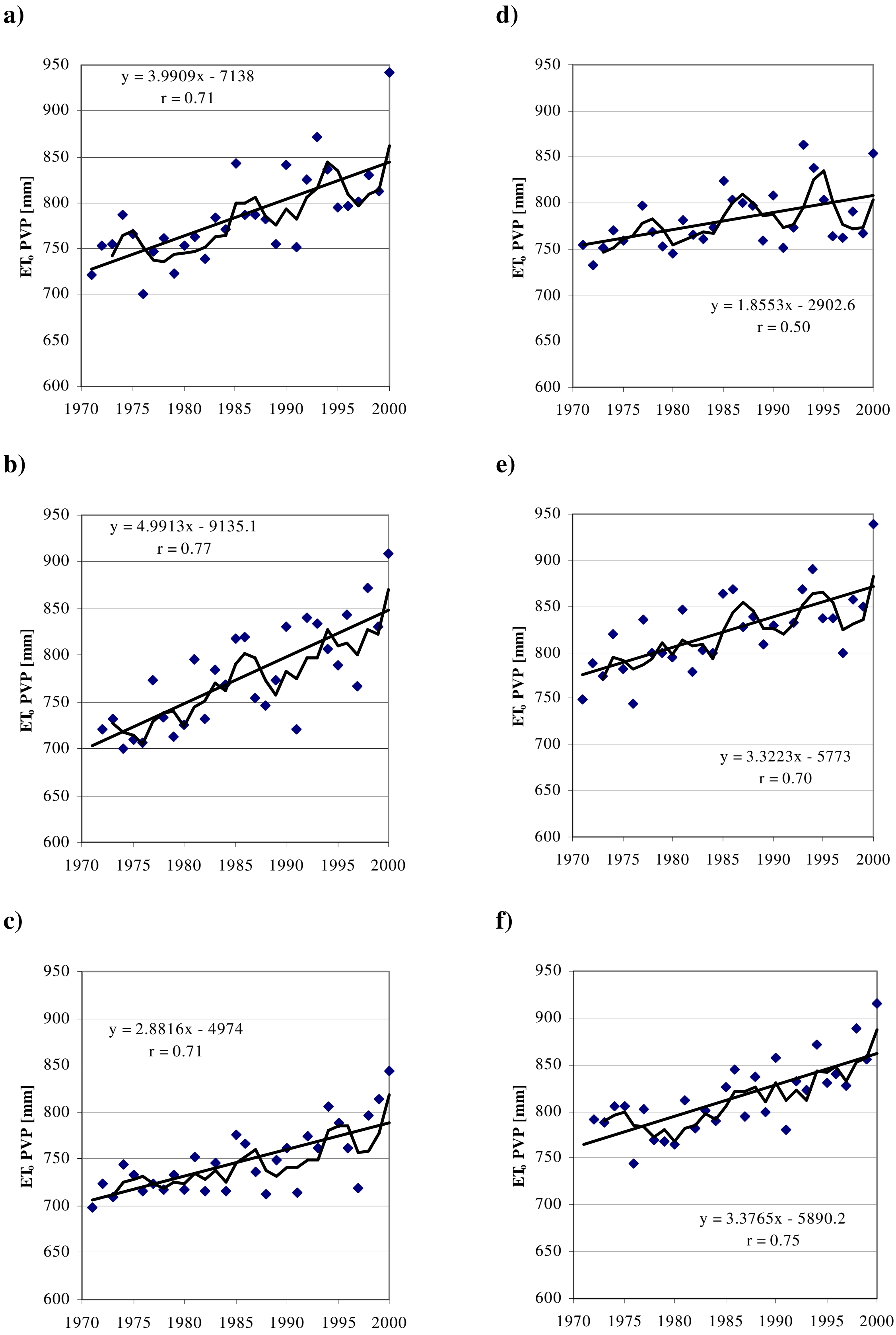

Fig. 5 Long-term tendency and 5-year moving average of FAO Penman-Monteith reference evapotranspiration for the Bulgarian Planning Regions: a) Northwestern; b) North Central; c) Northeastern; d) Southwestern; e) South Central; f) Southeastern

The greatest changes in FAO Penman-Monteith evapotranspiration of *PVP* are observed in North Central and Northwestern Regions – around three and two design application depths, the smallest ones – in Southwestern Region – one design application depth. The increase of ET_o of the other two studied periods per Planning Regions is half to one application depth for April-June and almost one application depth everywhere for July-August.

In 75% of the years $ET_{o\ PVP}$ is expected to be higher than 717.2 mm (Northeastern Region) – 796.5 mm (South Central Region), April-June ET_o – higher than 291.7 mm (Northeastern Region) – 326.2 mm (South Central District), and July-August ET_o – higher than 249.1 mm (North Central Region) – 277.7 mm (Southeastern Region) (Table 6).

Table 6 Values of FAO Penman-Monteith reference evapotranspiration at a particular probability per Planning Regions and important agricultural periods [mm]

Probability/Regions	North-western	North Central	North-eastern	South-western	South Central	South-eastern
Potential vegetation period						
25%	819.0	831.3	770.0	801.5	847.8	842.8
50%	784.0	772.8	744.7	770.3	828.3	806.3
75%	753.7	728.5	717.2	759.4	796.5	789.1
April-June						
25%	345.2	241.0	311.2	334.7	350.6	343.7
50%	322.4	325.1	297.7	323.0	336.4	321.4
75%	312.0	313.6	291.7	308.7	326.2	312.8
July-August						
25%	298.7	292.5	279.4	290.9	311.1	308.8
50%	272.5	274.5	263.7	275.8	297.2	290.7
75%	264.9	249.1	250.4	256.0	272.4	277.7

The regression equation (2) for the relationship between De Martonne aridity index and the evapotranspiration of winter wheat is a curve line at a significant correlation with a maximum at $DM = 40$ mm C^{-1} (Fig. 6). As it is difficult to determine crop evapotranspiration by measurements or complicated formulas, given the temperature and precipitation, De Martonne aridity index can be substituted in the suggested regression equation (2) and the latter to be used for estimation of winter wheat evapotranspiration:

$$ET_{wheat} = -0.18DM^2 + 13.66DM + 18.80 \qquad (2)$$

On Fig. 7 the deviations from the multi-year average value of yield are plotted against *DM* values. The correlation is represented by a correlation coefficient r = 0.53. This result is in conformity with the result of another study from abroad, which confirms that the hydro-thermal indices, in which precipitation is included directly, relate to yields by r in the range of 0.4-0.5 (Yakovleva [12]). The trend line crosses the y-axis at *DM* = 30 mm C^{-1}. Roughly, this means that high yields of winter wheat under rain-fed conditions can be obtained only when *DM* is higher than 30 mm C^{-1}.

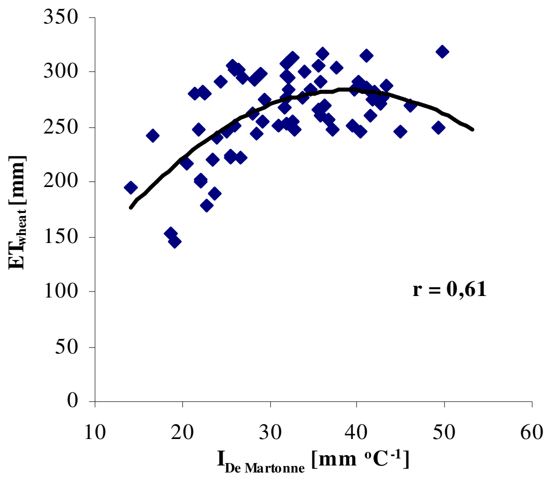

Fig. 6 Relation between winter wheat evapotranspiration and De Martonne aridity index

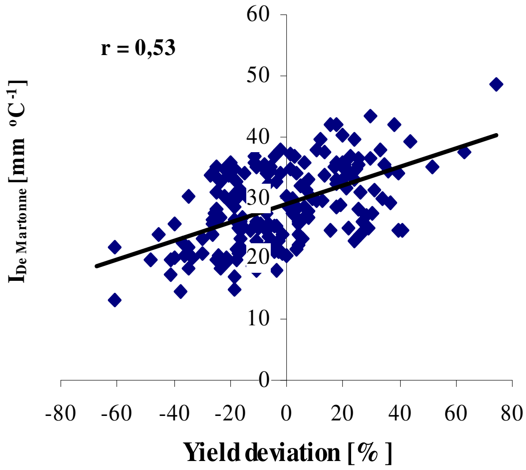

Fig. 7 Relation between winter wheat yield deviation from the average 30-year one and De Martonne aridity index

CONCLUSIONS

1. Bulgaria is situated in the sub-humid zone with insufficient water supply. Irrigation is inevitably necessary. The average climatic values of the potential vegetation period per Planning Regions are 22.7-25.6 mm C^{-1}, for April-June - 25.9-30.4 mm C^{-1} and for July-August - 15.6-22.7 mm C^{-1}. This specifies the conditions in Bulgaria as moist sub-humid in April-June and dry sub-humid in July-August.
2. South Central Planning Region and the southern parts of Southwestern Planning Region have the most unfavorable hydrothermal and evapotranspiration conditions. These conditions are most favorable in Northwestern Planning Region.
3. The 30-year (1971-2000) tendencies of De Martonne aridity index and FAO Penman-Monteith reference evapotranspiration provide reasons to predict future warming and drought in Bulgaria. The greatest changes are observed in North Central Planning Region – the reference evapotranspiration there has increased within the period 1971-2000 with around one design application depth (=60 mm) as for April-June, so for July-August period and 2.7 des. appl. depths for the potential vegetation period. The smallest changes are observed in Northeastern Planning Region – around half a design application depth as for April-June, so for July-August period and totally one des. appl. depth for the potential vegetation period.
4. High yields of winter wheat under rain-fed conditions can be obtained at De Martonne aridity index higher than 30 mm C^{-1}.
5. Crop evapotranspiration can be assessed trough the simple structured De Martonne aridity index by a regression equation of significant correlation (equation (2)).

ACKNOWLEDGEMENTS

The authors express their high appreciation to the Bulgarian National Science Fund for its financial support (Project NI SS 1605/06: Agroclimatic Resources in Bulgaria for Field Crop Cultivation under Irrigated and Rain-Fed Conditions).

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