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Relationships between the De Martonne aridity index and water requirements of some representative crops: A case study from Romania**

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A b s t r a c t. In Romania, arid regions occupy a large area especially in the south-eastern and southern regions *eg* the Romanian Danube Plain and Dobrogea, where most of the crops need to be irrigated during summer time. The method recommended by FAO uses the Penman-Monteith reference evapotranspiration (PM-ETo) to determine irrigation water requirements (IWRs) and crop evapotranspiration (ETc). Unfortunately, there are places in this country and most probably in the neighbouring countries with similar climate, where long-term records of solar radiation, wind speed and air humidity are missing. The purpose of this paper is to document the range of an aridity index, called De Martonne's aridity index (I_{ar}-DM) as it applies across the country of Romania, and to determine its relationship with irrigation water requirements of representative crops of Romania. I_{ar}-DM is the ratio between the mean values of precipitation (P) and temperature (T) plus 10°C, annually or monthly. The goal is to help preserve water resources through use of the index. I_{ar}-DM was calculated and averaged for a period of about 100 years and was plotted as maps by using the kriging interpolation method. I_{ar}-DM was correlated with both crop evapotranspiration and irrigation water requirements of the crops in this country. Inverse and strong regression equations were found between the correlated parameters. These relationships have a regional character and might help irrigation system designers and planners estimate the order of magnitude of IWRs and ETc by using I_{ar}-DM, and evaluate environmental water resources in temperate climate regions like areas in Romania and neighbouring countries, where only measurements of temperature and precipitation exist. 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 during summertime. The procedures used in the paper might be applied in many regions in Europe, and thus have widespread application.

K e y w o r d s: cereals, horticultural crops, crop water evapotranspiration, irrigation, water conservation

INTRODUCTION

In Romania arid regions occupy large areas, especially in the south-eastern and southern regions *eg* the Romanian Danube Plain and Dobrogea, where most of the crops need to be irrigated during summer time. There are regions to apply irrigation not only in the most arid locations but also in other areas in this country.

Aridity has been defined by various indicators, and some include both temperature and precipitation, such as De Martonne's aridity index (I_{ar}-DM), which is the ratio between the mean annual values of precipitation (P) and temperature (T) plus 10°C (De Martonne, 1926). Since then, other more complex aridity indexes, for instance involving reference evapotranspiration (ET_o), have been described *eg* Thornthwaite (1948). At the same time, there was no standard method to calculate ET_o until the late XXth century when the Penman-Monteith (Monteith, 1965; Jensen *et al.*, 1990) method got international recognition. Based on this method (PM-ET_o), crop evapotranspiration (ETc) and irrigation water requirements (IWRs) could be calculated worldwide (Allen *et al.*, 1998).

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In Romania, Cernescu (1961) used I_{ar}-DM to characterize the soil moisture regime throughout the country and made an aridity zoning map of Romania based on this index. He emphasized the correlation between the soil moisture regime and soil type. Botzan (1972), Paltineanu *et al.* (2000), Paltineanu and Mihailescu (2005), among others, reported data on arid or drought-affected areas, soil moisture dynamics, crop-water response, as well as IWRs for various regions of Romania.

Grumeza *et al.* (1989) reported a first zoning of the IWRs in Romania, but the areas studied were located mainly in the southern part of this country and the interpolation procedure of data was not reported. However, there are regions in this country with no measurements of solar radiation or sunshine hours, 2 m height wind speed or relative air humidity to calculate PM-ET_o. In other regions there are only short-term records on climate parameters of interest in irrigation design and planning like the ones discussed above. For such areas, some simple indexes need to be found to characterize the climate.

The purpose of this paper was to correlate I_{ar}-DM, which only needs temperature and precipitation data, with ETc as well as with the IWRs for some representative crops, in order to find simple but reliable relationships between these parameters.

These data are needed by planners in evaluating the use of water resources and in designing irrigation systems in regions possessing only basic climate parameters, in order to help preserve the environmental water resources.

MATERIALS AND METHODS

Romania is situated in the south-eastern part of Europe and has a temperate climate with high spatial variability due to some local factors like the presence of the Carpathian Mountains in its middle and the Black Sea to south-east.

Two hundred and fifty-two weather stations possessing on average about one century of climate records, mainly from 1900 to 2000, were studied for this objective. The spatial distribution of the weather stations across the country is relatively uniform. In general, all regions and relief forms possess weather stations measuring air temperature, air humidity, sunshine hours and/or solar radiation, precipitation, as well as wind speed at 10 or 2 m height. Soils reflect the geographical conditions across the country and are very divers.

The long term data were used in calculating the climatic parameters in order to be representative in time. However, the results obtained in this paper will only apply for current conditions, because future possible climate change could invalidate the extrapolations based on analysis of such long data sets.

I_{ar}-DM was calculated for these stations as both annual and monthly values according to De Martonne's method (De Martonne, 1926). I_{ar}-DM values were interpolated between stations using the kriging method (Matheron, 1963; Webster, 1985).

ETc was calculated for various crops for all weather stations from the PM-ET_o data (Monteith, 1965) and by help of the method of Allen *et al.* (1998) which used monthly crop coefficients. These crops were: cereals, sunflower (*Helianthus annuus* L.), soybean (*Glycine* max (L.) Merr.), sugar beet (*Beta vulgaris* (L.) saccharifera), alfalfa (*Medicago sativa* L.), potato (*Solanum tuberosum* L.), apple (*Malus domestica* L.), pear (*Pirus comunis*), cherry (*Prunus avium*), peach (*Prunus persica*), plum (*Prunus domestica* L.), apricot (*Armeniaca vulgaris*), strawberry (*Fragaria moschata*), table grapes (*Vitis vinifera*) and tomato (*Lycopersicum esculentum*). The fruit trees were treated in two situations, as mowed sod treatments between tree rows (designated in graphs and tables as *eg* apple – sod in the case of apple) and as clean cultivation treatments between tree rows (designated as *eg* apple – cultivated in the case of apple). The groundcover management systems of the fruit trees were considered in the two most common situations above, namely as mowed sod strips and clean cultivation strips, respectively, in order to agree with the procedure recommended by FAO (Allen *et al.*, 1998).

IWRs data for all these crops were calculated as differences between the effective precipitation (P) and ETc. The effective precipitation was estimated on a monthly basis by using the procedure described by Smith *et al.* (1992).

The method reported by Allen *et al.* (1998) was tested and validated using field experiments under the specific conditions of this country (Paltineanu, 2005).

As not all the weather stations measured the climatic parameters needed for the calculations of PM-ET_o for the whole period, regression equations between PM-ET_o and temperature-based parameters like the Thornthwaite method ET_o *ie* TH-ET_o was used to estimate PM-ET_o (Paltineanu *et al.*, 2006). Consequently, I_{ar}-DM, ETc and IWRs values were calculated for the whole XXth century.

For all weather stations, regression equations between I_{ar}-DM and ETc, as well as between I_{ar}-DM and IWRs were computed for annual values as well as for monthly values for July and August. All weather data pairs were considered in computing the regression equations, even if some crops were not grown in all regions, and if some of them, located in humid regions, had negative IWRs, which are not shown in graphs.

RESULTS

Spatial distribution of De Martonne's aridity index (I_{ar}-DM)

In Romania, I_{ar}-DM spatial distribution shows a high variability, with the lowest values (<20 mm $°C^{-1}$) for the driest conditions in the south-eastern areas of this country and the highest values in the upland regions: the Carpathian

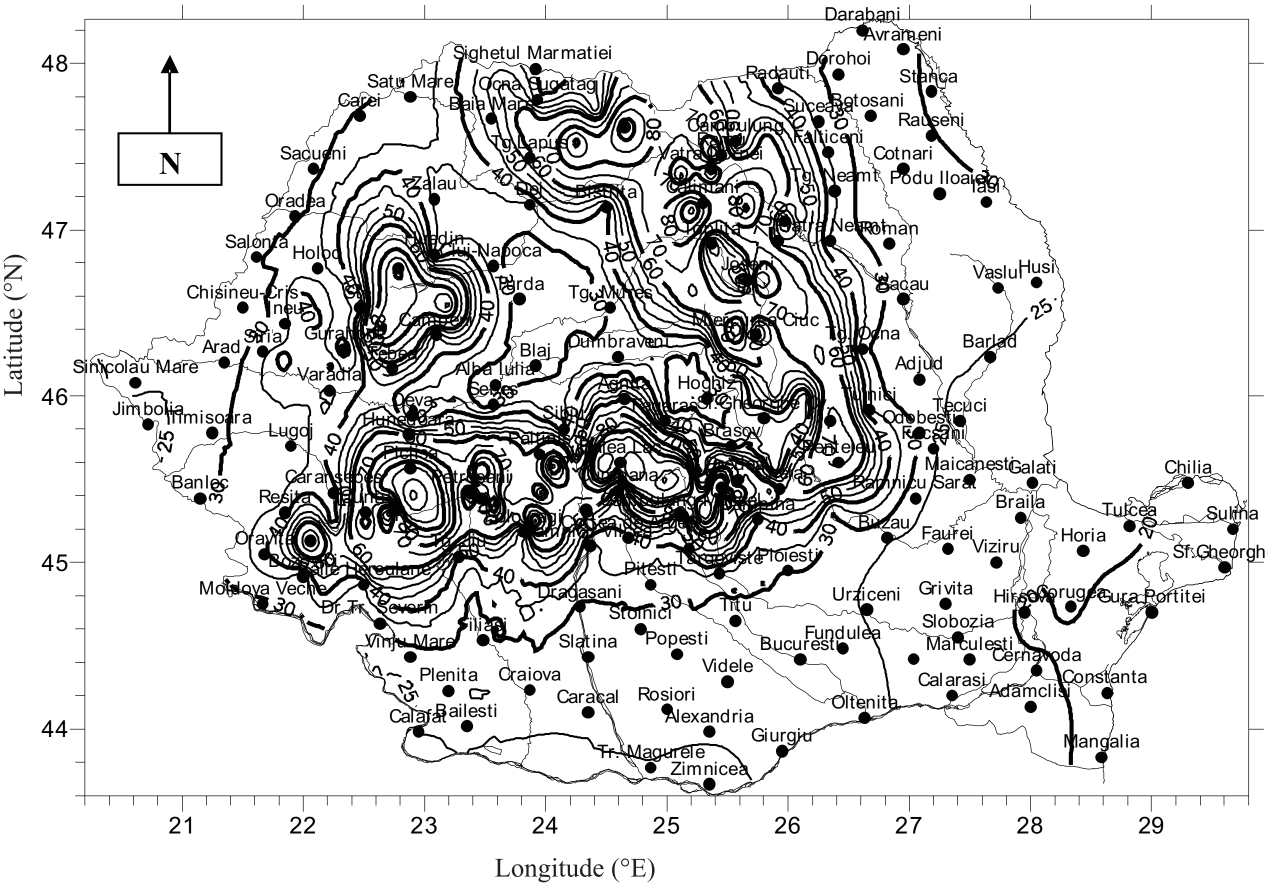


Fig. 1. Spatial distribution of De Martonne's aridity index (I_{ar}-DM, mm °C^{-1}, dotted curves) in Romania (Paltineanu and Mihailescu, 2005).

Mountains and plateaus areas (Fig. 1). However, the agricultural regions, which are represented by the major area of the Romanian Plain in its southern and central parts, the eastern part of the Moldova Plateau, the biggest part of the Tisa Plain, as well as the western part of the Transylvania Plateau, are characterized by 20-30 mm °C^{-1} I_{ar}-DM values. These acute-aridity regions of this country have a specific agricultural profile where cereals, vineyards, and some thermophile fruit tree species like apricot and peach trees prevail. Even if rain-fed agriculture is still performed in these regions, high yields can not be achieved without irrigation application.

The 40 and 50 mm °C^{-1} I_{ar}-DM isolines pass through the middle and high hilly regions, especially through the platforms and Pre-Carpathian areas. The 40 mm °C^{-1} I_{ar}-DM isoline approximately shows the way of equilibrium between the annual P and PM-ET_0 values. From these locations towards the high mountain peaks I_{ar}-DM values always increase and exceed 100 mm °C^{-1} in the alpine regions of the Carpathian Mountains, and reach as much as 160 mm °C^{-1} and even more.

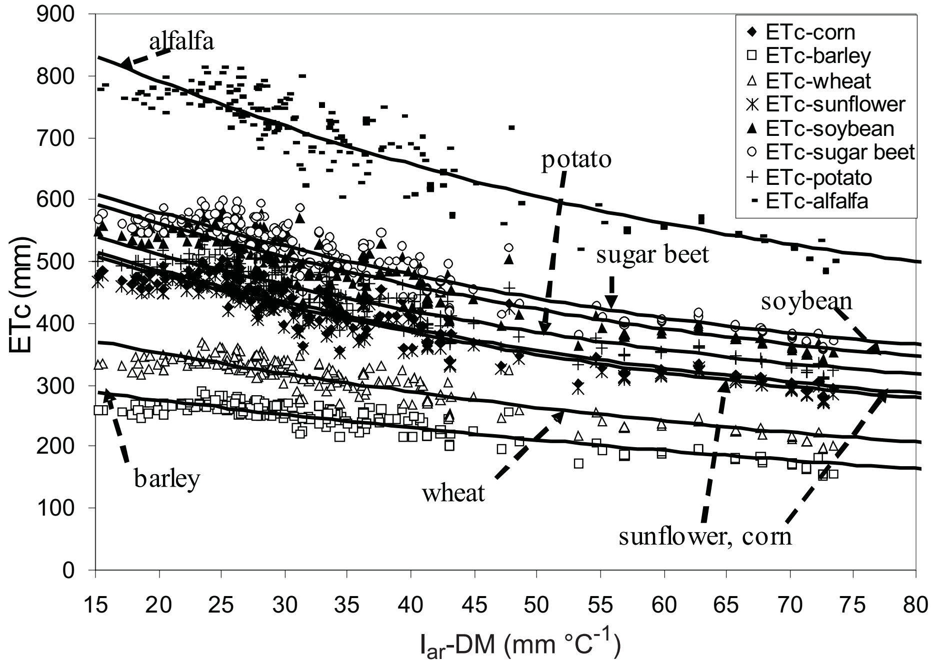
Relationships between I_{ar}-DM and ETc and between I_{ar}-DM and IWRs

Relationships between I_{ar}-DM *and* ETc

The regression equations obtained from these parameters show that there are inverse curve lines describing the correlation between I_{ar}-DM and ETc (Fig. 2).

According to the ETc magnitude, the two crop groups: field crops and horticultural crops, respectively, basically have values in the range of 450-700 mm of water, except for alfalfa due to its high water demand during the whole growing season. The latter has the first position in this graph with values as high as 600-800 mm for the I_{ar}-DM range of 15-60 mm °C^{-1}. In contrast, winter cereals show about 200-350 mm for the same I_{ar}-DM range. There are also two groups of horticultural crops, the fruit trees having a mowed sod space between tree rows (sod treatments) with ETc values as high as around 700 mm during the growing season for the most arid regions with I_{ar}-DM 15-20 (mm °C^{-1}), and the same fruit tree species with clean cultivation (cultivated) together with table grapes, strawberry and tomato which show lower values (about 450-550 mm).

a



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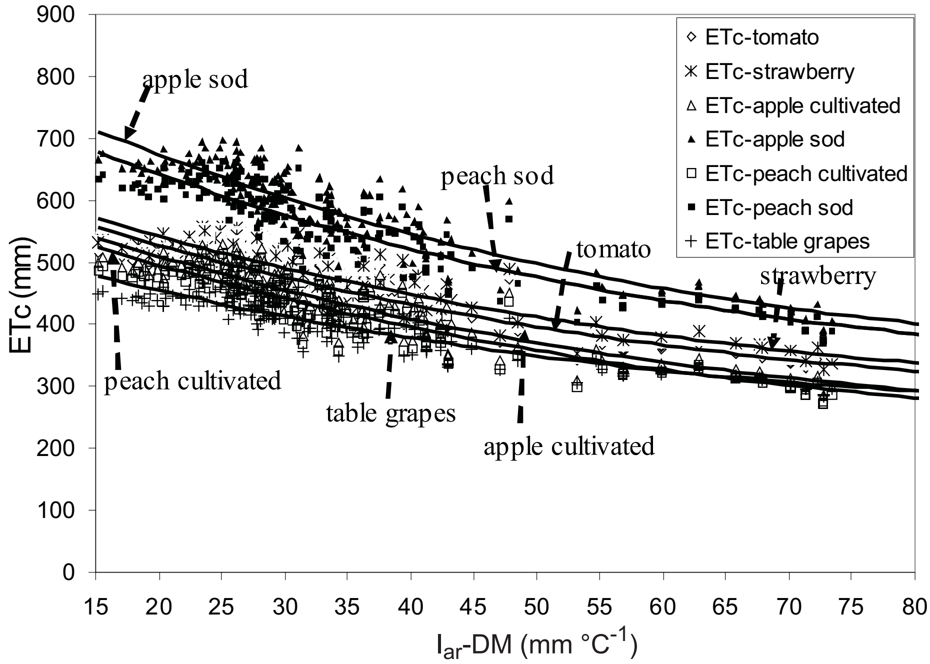
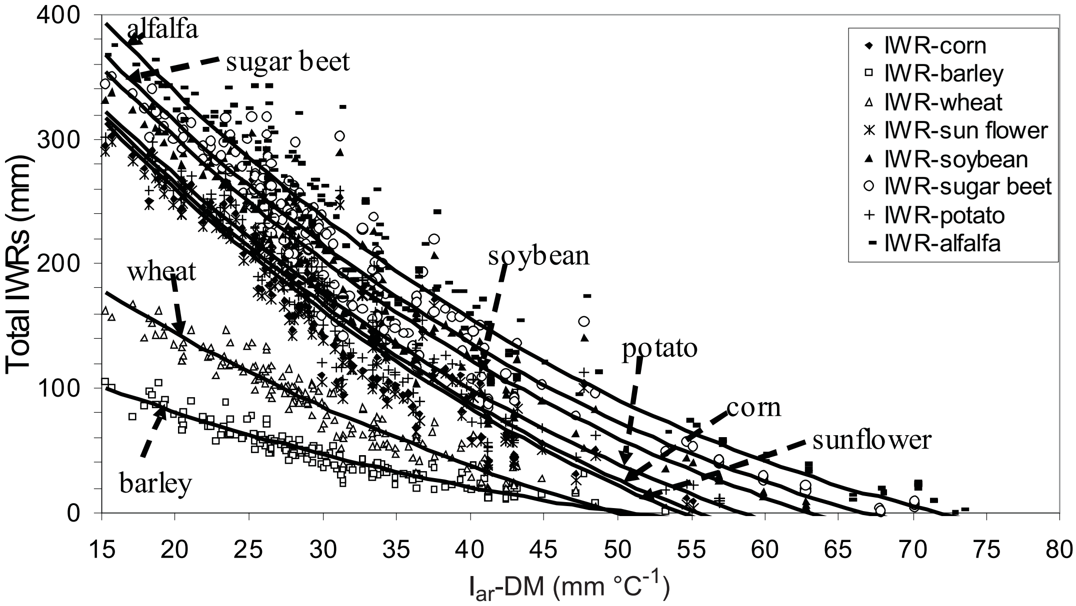


Fig. 2. Relationships between I_{ar}-DM and the total ETc for the studied crops; a – field crops, b – horticultural crops, in different regions in Romania during the growing season.

a



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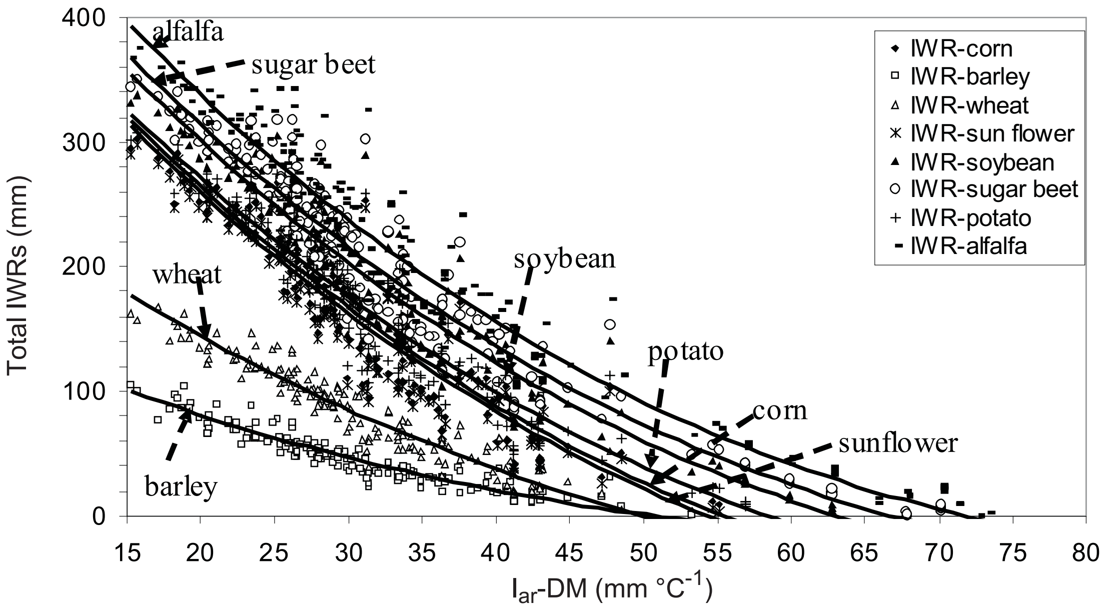


Fig. 3. Relationships between I_{ar}-DM and the total irrigation water requirements (IWRs, mm) for various crops; a – field crops, b – crops, in different regions in Romania during the growing season.

T a b l e 1. Parameters of degree-3 polynomial regression equations ($y=ax^3+bx^2+cx+d$) and the coefficient of determination (R^2) for the correlation between I_{ar}-DM (mm °C^{-1}) as the independent variable (x) and the total ETc (mm) under irrigation conditions during the growing season, for various crops in Romania; n = 252 of data pairs

Crops	Parameters of regression equations				
	a	b	c	d	R^2
			Field crops		
Alfalfa	-0.00020	0.0729	-10.626	976.58	0.9157
Corn	-0.00010	0.0530	-7.5476	616.64	0.9136
Sugar beet	-0.00010	0.0558	- 8,0376	718,75	0.9148
Soybean	-0.00010	0.0551	- 8.0109	701.32	0.9156
Sunflower	-0.00010	0.0520	- 7.4942	609.33	0.9156
Wheat	-0.00006	0.0271	- 4.5962	433.59	0.9219
Barley	-0.00002	0.0135	- 2.9932	329.99	0.9189
Potato	-0.00010	0.0496	- 7.2123	636.54	0.9144
			Horticultural crops		
Apple - cultivated	-0.00010	0.0557	-8.0398	650.40	0.9157
Apple - mowed sod	-0.00020	0.0722	-10.249	852.16	0.9138
Peach-cultivated	-0.00010	0.0546	-7.8941	633.19	0.9154
Peach-mowed sod	-0.00020	0.0678	-9.6513	810.08	0.9142
Strawberry	-0.00010	0.0495	-7.3321	670.11	0.9159
Table grapes	-0.00010	0.0427	-6.1101	561.00	0.9135
Tomatoes	-0.00010	0.0521	-7.5585	659.18	0.9143

T a b l e 2. Parameters of degree-3 polynomial regression equations ($y=ax^3+bx^2+cx+d$) and the coefficient of determination (R^2) for the correlation between I_{ar}-DM (mm °C^{-1}) as the independent variable (x) and the total IWRs (mm) during the growing season, for various crops in Romania; n = 252 of data pairs

Crops	Parameters of regression equations				
	a	b	c	d	R^2
			Field crops		
Alfalfa	-0.0003	0.1248	- 15.680	604.17	0.9640
Corn	-0.0003	0.1209	- 15.112	520.37	0.9641
Sugar beet	-0.0003	0.1221	- 15.310	573.80	0.9644
Soybean	-0.0003	0.1221	- 15.312	560.89	0.9645
Sunflower	-0.0003	0.1208	- 15.112	515.71	0.9647
Wheat	-0.0002	0.0755	- 9.2763	301.21	0.9774
Barley	-0.0002	0.0535	- 5.7431	175.40	0.9569
Potato	-0.0003	0.1183	- 14.771	521.04	0.9645
			Horticultural crops		
Apple - cultivated	-0.0003	0.1196	-14.952	474.56	0.9650
Apple - mowed sod	-0.0003	0.1277	-16.047	584.15	0.9632
Peach-cultivated	-0.0003	0.1169	-14.588	451.22	0.9652
Peach-mowed sod	-0.0003	0.1250	-15.682	560.69	0.9637
Strawberry	-0.0003	0.1091	-13.549	417.64	0.9660
Table grapes	-0.0003	0.1063	-13.161	417.05	0.9657
Tomatoes	-0.0003	0.1197	-14.962	529.58	0.9644

Irrigation is usually applied in this country in regions of up to 35 mm °C^{-1} I_{ar}-DM values, where IWRs range between about 400 and 600 mm. Extending the Fisher test from linear to curvilinear regressions, it was found that all the equations obtained are highly significant, showing values of the coefficients of determination (R^2) higher than 0.90 (Table 1) for the crops investigated.

Relationships between I_{ar}-DM *and* IWRs

The annual values of I_{ar}-DM and the values of IWRs over the entire growing season were correlated and inverse curvilinear regression equations were also found for all the crops studied (Fig. 3).

For the two groups of crops, the lowest (from 15 to 20 mm °C^{-1}) I_{ar}-DM values correspond to IWRs values of up to 240-400 mm for the field crops, except winter cereals with the smallest values (80-190 mm) due to their specific period of vegetation, and to IWRs values of 180-360 mm for the horticultural crops. IWRs decrease to about 100 to 200 mm for the 35 mm °C^{-1} I_{ar}-DM in the case of the field crops, except for winter cereals which show 20-80 mm and should not be irrigated in these regions due to economical reasons, and to about 60-160 mm for horticultural crops. From the horticultural crops, the mowed-sod fruit tree species and tomato present the highest values, while the other treatments and crops show the lowest ones. The best fit for the regression equations is also the degree-3 polynomial type. Their parameters are shown in Table 2, where one can see the higher (over 0.96) R^2 values.

The correlations between the monthly I_{ar}-DM and IWRs values for the major months in irrigation application, July and August, are depicted in Figs 4 and 5, respectively.

The regression equations obtained for July have also an inverse aspect, but degree-2 polynomial type are best fitted with R^2 as high as 0.98 and 0.99 (Fig. 4, Table 3). Field crops have IWRs values between about 60 and 130 mm month^{-1} for the regions with I_{ar}-DM range of 15-36 mm ºC^{-1} during July, and the crops values are close to each other. According to the magnitude of IWRs, there are the same two groups of horticultural crops for July with values of about 30 to 125 mm month^{-1} *ie* tomato and the mowed sod treatments of the fruit trees showing higher IWRs values, and strawberry, table grapes and the clean cultivation treatments of the fruit trees showing lower IWRs values.

IWRs values are lower in August (Fig. 5) compared with July, and the differences between the two months are small (Table 4). In August, IWRs for corn, soybean, sugar beet and potato are close, and alfalfa needs the largest amounts of irrigation water, while sunflower, the lowest.

Testing of the relationships between I_{ar}-DM and ETc and between I_{ar}-DM and IWRs

The relationships obtained with the method above have been tested with data from two climates, the temperate climate from Romania in 15 experimental fields for a long-term period (Grumeza and Kleps, 2005), and a neighbour Mediterranean – temperate climate in the northern part of Greece, the Gallikos watershed (Paltineanu *et al*., 1999).

Testing of the ETc *relationships in the temperate climate of Romania*

In Romania, ETc obtained in field experiments for wheat, corn, alfalfa, sunflower, sugar beet, potato and soybean and reported by Grumeza and Kleps (2005) have been compared with ETc for the same crops obtained by using the relationships from Table 1 for each crop (Fig. 6).

Winter cereals have the lowest ETc and are located on the 1:1 line in the lowest position in Fig. 6. The regression equation between these parameters is highly significant and the difference between the regression line and the 1:1 line decreases towards the highest ETc values. In general, the experimental ETc values are higher than the calculated ETc values, but this can be explained by water seepage beyond plant roots in the field after strong rainfalls.

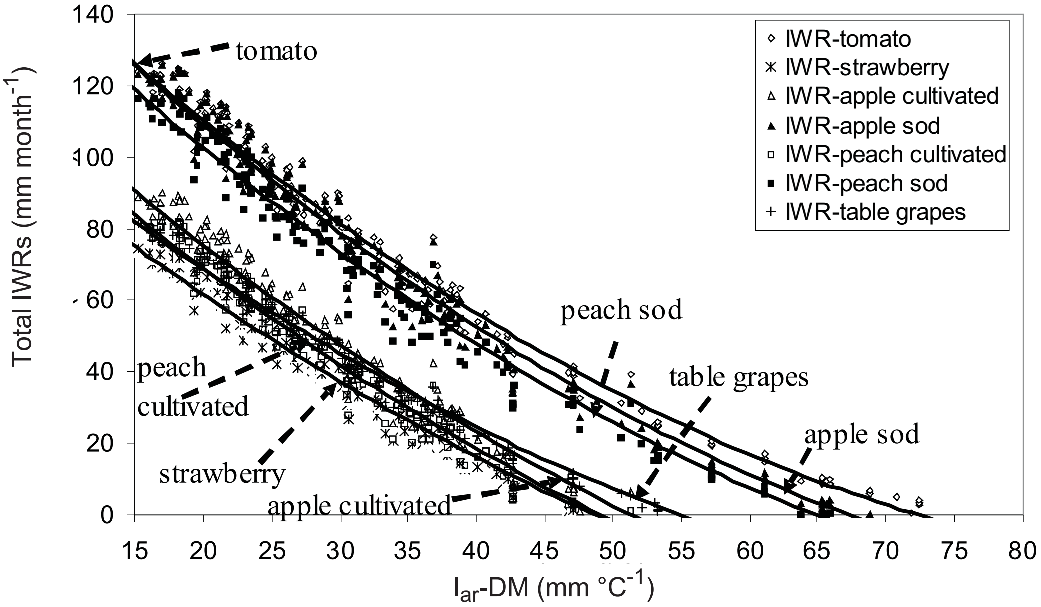
For each crop tested, Table 5 presents the difference and the ratio between the experimental and calculated ETc, as well as the standard error of estimates (SEE).

Except for alfalfa which shows a negative ETc difference and less than 1 ETc ratio, all the other crops have, as already mentioned, higher experimental ETc values than calculated ETc values, and the explanation has been given above. Usually, the experimental ETc is by about 2% (potato) to 36% (corn) higher than the calculated ETc. For the temperate climate specific to Romania, this would validate ETc relationships presented in Tables 1- 4, because IWRs are a component of ETc.

Testing of the IWRs *and* ETc *relationships in the Mediterranean-temperate climate*

For some crops with available data *ie* corn, alfalfa, tomato, sugar beet, sunflower and grape, the comparison between reported IWRs from 7 different places in the Gallikos watershed, northern Greece (Paltineanu *et al*., 1999) and estimated IWRs from the relationships obtained using I_{ar}-DM Romanian data, as well as their difference, ratio and standard errors of estimate are shown in Table 6. The tested periods are July, August and the growing season. Even if the climate is different enough from the climate in Romania (the Galikos watershed in Greece is about 500 km further south from Romania) the differences between IWRs, reported versus calculated, are not too high in July. All the six crops

a



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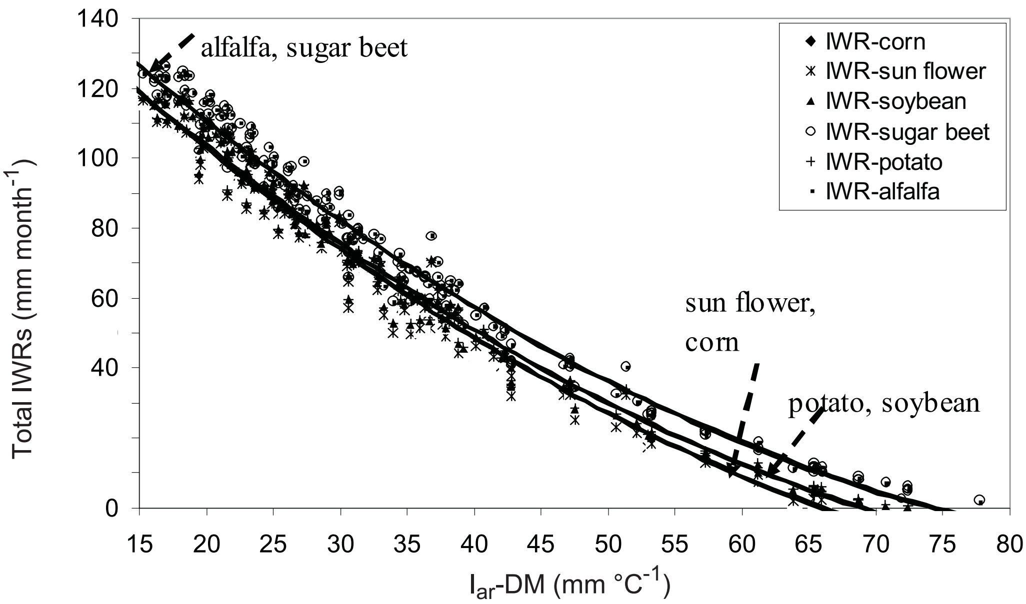

Fig. 4. Relationships between I_{ar}-DM and the irrigation water requirements (IWRs, mm) for various crops; a – horticultural crops, b – field crops, in different regions in Romania during July.

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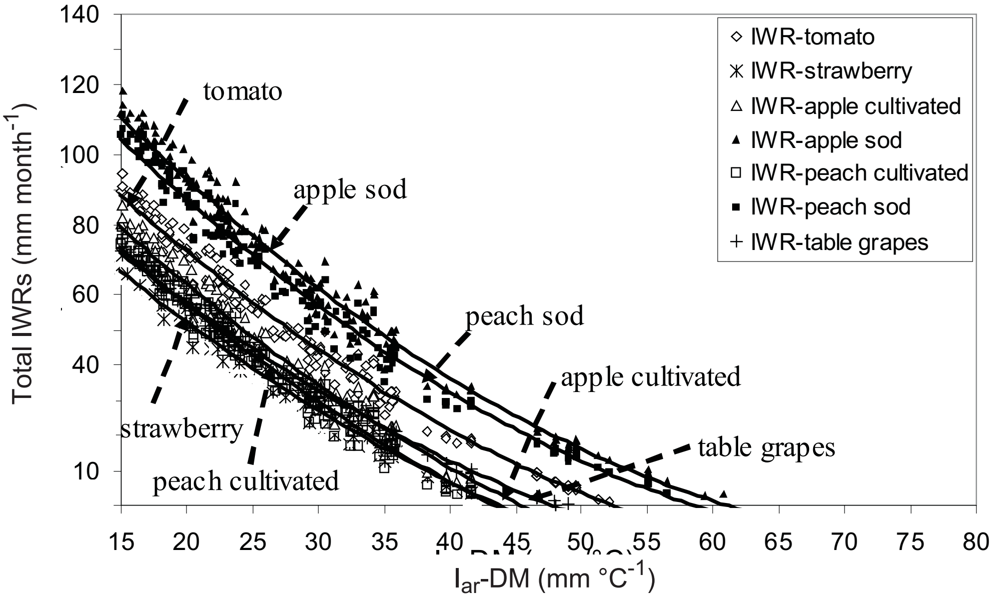

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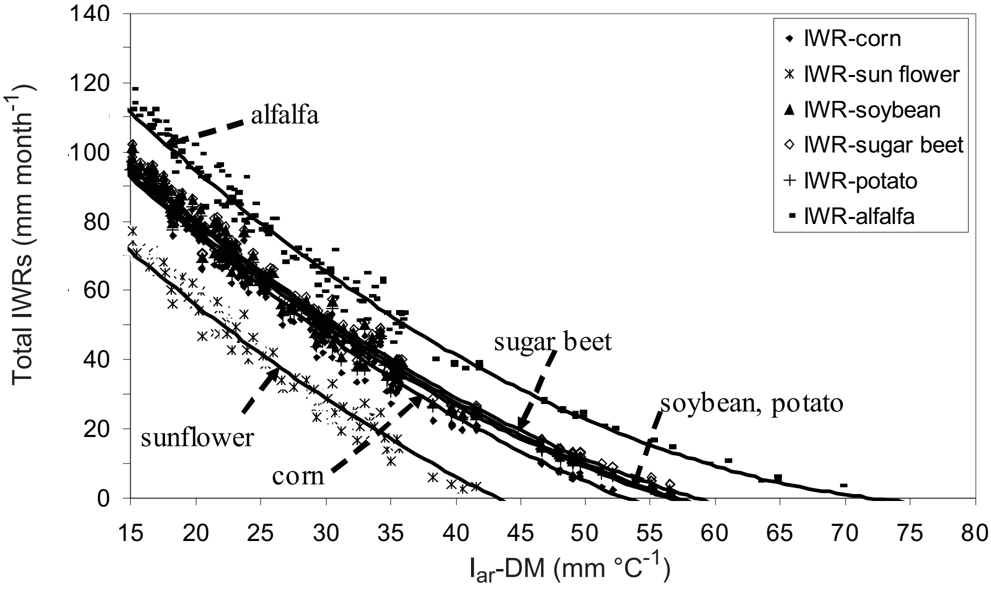

Fig. 5. Relationships between the monthly values of I_{ar}-DM and the irrigation water requirements (IWRs, mm) for various crops; a– horticultural crops, b – field crops, in different regions in Romania during August.

T a b l e 3. Parameters of degree-2 polynomial regression equations ($y=ax^3+bx^2+cx+d$) and the coefficient of determination (R^2) for the correlation between I_{ar}-DM (mm °C^{-1}) as the independent variable (x) and the total IWRs (mm) during July, for various crops in Romania; n = 252 of data pairs

Crops	Parameters of regression equations			
	a	b	c	R^2
		Field crops		
Alfalfa	0.0182	- 3.7637	178.59	0.9906
Corn	0.0182	- 3.8078	171.62	0.9902
Sugar beet	0.0182	- 3.7496	178.33	0.9908
Soybean	0.0180	- 3.7197	170.82	0.9910
Sunflower	0.0182	- 3.7977	171.56	0.9903
Potato	0.0179	- 3.709	170.68	0.9910
		Horticultural crops		
Apple - cultivated	0.0172	-3.6263	140.77	0.9915
Apple - mowed sod	0.0188	-3.9492	180.44	0.9891
Peach-cultivated	0.0167	-3.5265	132.63	0.9922
Peach-mowed sod	0.0184	-3.8494	172.30	0.9899
Strawberry	0.0156	-3.2233	119.84	0.9942
Table grapes	0.0155	-3.1379	125.28	0.9947
Tomatoes	0.0184	-3.8030	178.99	0.9903

T a b l e 4. Parameters of degree-3 polynomial regression equations ($y=ax^3+bx^2+cx+d$) and the coefficient of determination (R^2) for the correlation between the monthly values of I_{ar}-DM (mm °C^{-1}) as the independent variable (x) and the total IWRs (mm) during August, for various crops in Romania; n = 252 of data pairs

Crops	Parameters of regression equations			
	a	b	c	R^2
		Field crops		
Alfalfa	0.0263	- 4.2385	168.93	0.9907
Corn	0.0254	- 4.1607	149.32	0.9917
Sugar beet	0.0251	- 4.0494	151.04	0.9919
Soybean	0.0252	- 4.0840	150.90	0.9919
Sunflower	0.0238	- 3.9091	124.57	0.9934
Potato	0.0250	- 4.0499	148.75	0.9921
		Horticultural crops		
Apple - cultivated	0.0247	-4.0968	135.02	0.9924
Apple - mowed sod	0.0270	-4.4531	171.18	0.9899
Peach-cultivated	0.0241	-3.9833	127.41	0.9931
Peach-mowed sod	0.0264	-4.3385	163.45	0.9906
Strawberry	0.0226	-3.6437	116.12	0.9941
Table grapes	0.0227	-3.6139	120.92	0.9937
Tomatoes	0.0247	-4.0269	143.03	0.9924

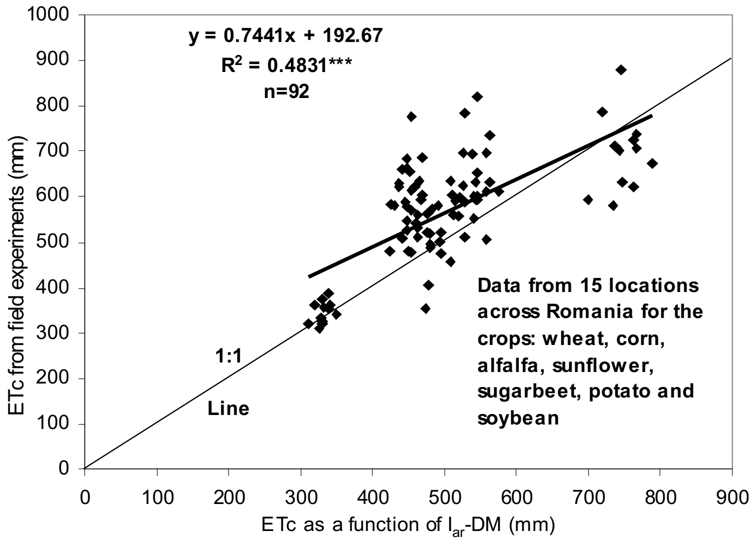

Fig. 6. Correlation between ETc from field experiments in Romania, reported by Grumeza and Kleps (2005), and estimated ETc from the relationships obtained using Romanian I_{ar}-DM data for some common crops, in the growing season. R^2 is the coefficient of determination and *** means highly significant for 99.9% of probability.

T a b l e 5. Difference, standard error of estimate (SEE) and ratio between the experimental ETc data (mm) obtained in 15 different locations across Romania and calculated ETc data (mm) for various crops during the growing season under irrigation conditions

Crop	ETc difference (mm)	ETc SEE (mm)	ETc ratio
Wheat	14.3	23.6	1.04
Corn	163.6	175.2	1.36
Alfalfa	-52.2	86.5	0.93
Sunflower	123.3	122.0	1.27
Sugar beet	107.0	118.4	1.20
Potato	7.9	54.7	1.02
Soybean	69.3	93.5	1.13

T a b l e 6. Comparison between reported IWRs from 7 different places in the Gallikos watershed, northern Greece (after Paltineanu *et al.*, 1999) and estimated IWRs from the relationships obtained using I_{ar}-DM Romanian data for some common crops studied. as well as their difference, ratio and standard errors of estimate

Crop studied	IWRs difference (mm)			IWRs ratio			IWRs SEE (mm)		
Period*	July	August	GS*	July	August	GS	July	August	GS
Corn	26.0	18.6	152.9	1.25	1.20	1.66	31.7	26.1	165.8
Alfalfa	18.4	7.3	257.4	1.17	1.07	1.84	25.7	20.5	271.9
Tomato	18.5	-56.8	54.9	1.17	0.40	1.23	25.9	57.6	75.3
Sugar beet	18.4	22.9	203.5	1.17	1.23	1.72	25.7	29.7	217.6
Sunflower	36.6	-17.4	239.1	1.33	0.78	2.04	41.1	21.0	249.1
Grape	-11.5	-26.7	1.9	0.89	0.66	1.03	16.7	28.7	41.5

*GS – growing season.

studied show higher reported IWRs than calculated IWRs in July and the growing season, and only three crops showed such data in August. The ratio ranged between 117 and 133% in July, from 40 to 123% in August, and from 103 to 204% in the growing season.

These IWRs differences can also be attributed to the different periods of the growing season in the two countries, and the longer one in Greece explains why the higher values occur in this country. The correlation between the reported and calculated IWRs values and their comparison for July and August can also be viewed in Fig. 7. The regression line for July has a higher position versus the 1:1 line, while the one for August has rather a lower position versus the 1:1 line.

Despite the important climatic differences between the two countries, the regression line between reported ETc and calculated ETc is close to the 1:1 line, and the medium-low coefficient of determination (R^2) is still highly significant for the growing season (Fig. 8).

Even if close similarities between the two countries were not expected, it was found that the relationships obtained in this paper could be applied in different climates from the south-eastern part of Europe.

DISCUSSION

The method of Allen *et al.* (1998) to estimate ETc and IWRs was confirmed in many places throughout the world including in this country (Paltineanu 2005), but minimum daily relative air humidity data to estimate crop coefficients (Kc) were needed along with weather data to compute PM-ET_o. Unfortunately, there are places in this country, and most probably in neighbouring countries with similar climates, where long-term records of such data are missing. Countries showing similar climate conditions would be: the Republic of Moldova, the south-western regions of Ukraine, the northern part of Bulgaria, the eastern part of Hungary, and the north-eastern regions of Serbia. Even today, when automatic weather stations that measure many meteorological parameters are widely spread over in many countries, they do not have and can not replace long-term data required to process reliable climate data over time. In this respect, this paper tries to overcome those shortcomings and to help estimate the order of magnitude for both ETc for the entire growing season as well as IWRs for the months when irrigation is needed with acuity *ie* July and August, as well as for the whole season, by using I_{ar}-DM calculated for the same period or month.

The water required for irrigation in these regions is usually taken from rivers, especially the Danube River and other large tributary streams, or fresh water lakes during summer time. However, in summertime river discharge has minimum values, and there is a competition for fresh water between various consumers. This study could thus help hydrologists and planners make proper decisions concerning how to use scarce water resources. Seen like this, this paper applies to Europe in general.

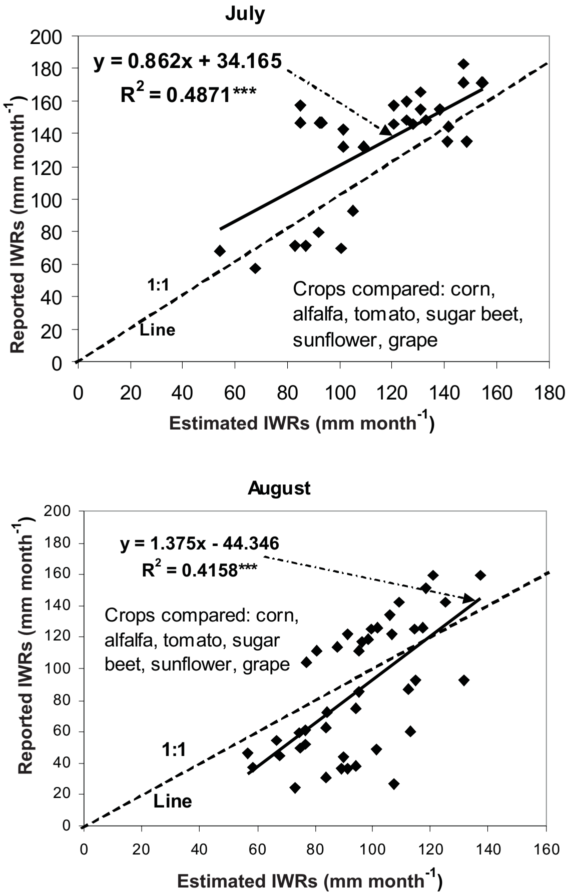

Fig. 7. Correlation between the mean monthly values of reported IWRs (after Paltineanu *et al.*, 1999) from the Gallikos region, Greece, and estimated IWRs from the relationships obtained using Romanian I_{ar}-DM data for some common crops studied for July

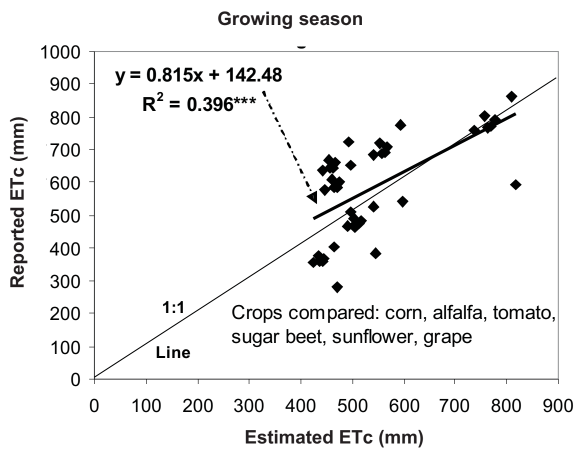

Fig. 8. Correlation between the reported ETc from the Gallikos region, Greece (after Paltineanu *et al.*, 1999) and estimated ETc from the relationships obtained using Romanian I_{ar}-DM data for some common crops studied for the growing season. Explanations as in Fig. 6.

CONCLUSIONS

1. In Romania, I_{ar}-DM spatial distribution showed a high variability, with the lowest values (< 20 mm °C^{-1}) for the driest conditions in the south-eastern areas of this country. Irrigation is usually applied in the regions with I_{ar}-DM values of 15 - 35 mm °C^{-1}.

2. There were strong inverse, curved lines describing the correlation between I_{ar}-DM and ETc through regression equations.

3. Inverse curvilinear regression equations between the annual values of I_{ar}-DM and of IWRs over the entire growing season were also found for all crops studied. The lowest I_{ar}-DM values corresponded to the highest IWRs values. Highly significant regression equations also were found between the monthly values of July and August and I_{ar}-DM and IWRs.

4. The testing of these relationships in various locations proved that they could be useful for hydrologists. These relationships have a regional character and might help irrigation system designers and planners estimate the order of magnitude of IWRs and ETc by using I_{ar}-DM. They could be used to evaluate environmental water resources in temperate climate regions like areas of Romania and neighbouring countries, where only measurements of temperature and precipitation exist.

5. Due to the competition for water between various consumers, this study might help hydrologists and planners make proper decisions concerning how to use scarce water resources during summertime; by doing this over a large area, results of the paper can be applied to Europe in general.

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