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ESTIMATING REFERENCE EVAPOTRANSPIRATION AND IRRIGATION WATER REQUIREMENTS IN THE GALLIKOS RIVER BASIN, GREECE*

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A b s t r a c t. Reference evapotranspiration was calculated using five various types of estimating methods. The Hargreaves and Thornthwaite methods produced close, strongly-correlated ET_O values to those yielded by the standard Penman-Monteith method. For these reasons and due to their simplicity in calculations, i.e., few parameters needed, these two methods are recommended for in order to determine crop water as well as irrigation water requirements for the Gallikos watershed. Reference evapotranspiration isolines as yielded by the Hargreaves method showed a characteristic pattern, by decreasing from the eastern to the western part within the Gallikos watershed. Crop water requirements divided crops into more groups. These crops can be an alternative for the present situation which is mainly characterised by wheat cropping. For shortage in irrigation water supply special scenarios, not developed here, should be followed.

K e y w o r d s: evapotranspiration, irrigation, cropwater requirements

INTRODUCTION

The Gallikos watershed is located along the river similarly named, in the northern part of Greece, around 41^0 latitude north. Within and around this watershed there are seven wea-ther stations situated at various altitudes that were used to provide data for reference evapotranspiration (ET_O) calculations. These stations are: Thessaloniki (32 m altitude), Sindos (7 m), Lahanas (634 m), Melanthion (490 m), Metaxohori (277 m), Ano-Theodoraki (480 m), and Doirani (150 m).

Estimating ET_O in order to evaluate irrigation water requirements is an important aspect needed for crop water management. Many specialists recommend the Penman-Monteith method as a standard method to calculate ET_O, unless lysimetric measurements are available [7,9,10].

The purpose of this paper is to: (i) evaluate ET_O by five different methods as well as crop and irrigation water requirements for the whole agricultural area within the Gallikos watershed, (ii) compare the estimation methods used and recommend the most practical for use, and (iii) provide the irrigation users with ET_O-isoline maps and crop coefficients for every month of interest in applying irrigation water.

MATERIAL AND METHODS

The five methods used to calculate ET_O as described by Jensen *et al.* [10] were as follows (i) two combination equation methods, Penman

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-Monteith (PM) [1,2,11], and FAO 24 Corrected Penman (FAO 24 CP), [5], (ii) two temperature-based methods, Hargreaves (H) [6,8] and Thornthwaite (TH) [22] and (iii) a radiation method, Priestley-Taylor (PT) [17].

Mean daily values of month periods for air temperature (*Tm*), relative humidity (*RH*), wind speed (*U*), and solar fraction (*n/N*) were used to compute PM-ET_O with the help of the CROPWAT Program [20]. Temperature data was available for each weather station, but only *RH* and *U* data only in Thessaloniki, Sindos and Lahanas. For the other four sites *RH* and *U* data was collected from the Lahanas weather station that is situated in their proximity. Solar radiation (*Rs*), was only measured in Thessaloniki (University area) and Sindos (Land Reclamation Institute). However, because the first site is located on a polluted coastal area [18], the measurements from Sindos were considered more representative for the whole watershed and therefore used for all the other six sites, as recommended by Jensen *et al.* [10]. Because the CROPWAT Program needs *n/N* as input data, this was derived from the *Rs* equation:

$$Rs = (a+b\ (n/N))Ra \quad (1)$$

using locally-calibrated *a* and *b* coefficients according to the values reported by Panoras and Mavroudis [13], where *Rs* is the solar radiation (MJ/m^2/d), and *Ra* is the extraterrestrial radiation (MJ/m^2/d).

The PM combination equation used in the CROPWAT Program to compute ET_O (mm/-day) was given in the CLIMATE for CROPWAT Program [21]:

$$ET_O=(0.408\Delta(Rn-G)+900\gamma\ U(e_a-e_d)/(Tm+273))/(\Delta+\gamma(1+0.34U)) \quad (2)$$

where *Rn* - the net radiation at crop surface (MJ/m^2/d), *G* - the soil heat flux (MJ/m^2/d), *Tm*- average temperature (^{o}C), *U*- wind speed at 2 m height (m/s), (e_a-e_d) - vapour pressure deficit (kPa), Δ - slope of the vapour pressure curve (kPa/C), γ- psychrometric constant (kPa/C).

The FAO 24 CP method formula [5] was:

$$ET_O= c\ (W\,Rn + (1-W)\,f(U)\ (e_A - e_d)) \quad (3)$$

where *W*- temperature-related weighting factor, *Rn*- solar radiation (mm/day), *f(U)*- wind-related function ($f(U)$=0.27(1+U/100), U(Km/-day)), (e_A - e_d) in mb, and *c*- an adjustment factor to compensate for the effect of day and night weather conditions.

The ET_O -H method only needs maximum and minimum *T* values [7]:

$$ET_O=0.0023\ Ra\ (Tm + 17.8)\ TD^{0.5} \quad (4)$$

where ET_O and *Ra* are in the same units (mm/d), and *TD* is the temperature deficit (mean maximum minus mean minimum *T*, (^{o}C)), and *Tm* as before. The ET_O -TH method [22] used the formula:

$$ET_O(\text{mm/month}) = 16\ Ld\ (10Tm\,/\,I)^a \quad (5)$$

where *Ld* is a correcting factor as a function of latitude and month for actual day length and days in a month, and *I* is defined by:

$$I = \sum_{j=1}^{12} \left(T_j\,/\,5\right)^{1.514} \quad (6)$$

and

$$a = 675\ 10^{-9}\ I^3 - 771\ 10^{-7}\ I^2 + 1792\ 10^{-5}\ I + 0.49239\,. \quad (7)$$

The ET_O - PT method was calculated according to Jensen *et al.* [10]:

$$ET_o = (I\,/\,\lambda)\left(\alpha\ \Delta(Rn-G)\,/\,(\Delta+\gamma)\right) \quad (8)$$

where α = 1.26 as recommended by Davies and Allen [4] and Jensen *et al.* [10], λ- the latent heat of vaporisation (kJ/kg) as a function of temperature. In a short period in 1988, Papaioannou *et al.* [15] found values of 1.58 for coefficient α, much larger than that recommended by Davies and Allen [4] or Jensen *et al.* [10] that was used here (1.26). The other symbols have the same significance as in Eq. (2).

ET_O values after being compared to the standard-method results were displayed for each irrigation-desired month (May-September) within the growing season, as isoline maps created by help of the SURFER Program.

Crop water requirements using both existing experimentally-obtained crop coefficients for seven crops: corn, cotton, alfalfa, tobacco, tomato, sugarbeet and grape [16] and estimated crop coefficients by help of the method described by Doorenbos and Pruitt [5] for sunflower were calculated for the FAO 24 Corrected Penman method. These requirements were utilised to compute crop coefficients for the Hargreaves and Penman-Monteith methods, as well as irrigation water requirements using effective rainfall calculated according to the USDA Soil Conservation Service Method [20].

RESULTS AND DISCUSSIONS

Comparisons of ET_O values obtained by the five methods used

Multiannual mean daily ET_O values per month periods calculated by the five methods are shown in Fig. 1 for all sites studied. As a general rule the TH and PM methods produced the lowest ET_O values, while the PT and FAO 24 CP methods yielded the highest ones, especially at the weather stations based on the Sindos-measured *Rs,* (Fig. 1). For all sites considered the minimum ET_O values occurred in Thessaloniki, irrespective of the method used. The large differences between ET_O values calculated by these two groups of methods, as well as sites, that occurred in the above mentioned weather stations are due to differences in *Rs* between Thessaloniki and Sindos, as earlier discussed by Sahsamanoglu *et al.* [19]. The ET_O values obtained through the H method are close to the PM results for all weather stations investigated, especially in Sindos and Lahanas (Fig. 1). However, for all sites studied the H method produced slightly larger ET_O values than the PM method and is consistent with data found by Amatya *et al.* [3]. For the peak month (July), ET_O values calculated by all methods ranged from: 5.3 to 6.0 mm/d in Thessaloniki, 5.2 to 7.3 mm/d in Sindos, 4.4 to 6.8 mm/d in Lahanas (highest altitude), 4.5 to 6.9 mm/d in Melanthion and Ano-Theodoraki, 4.9 to 7. I mm/d in Metaxohori, and 4.9 to 7.2 mm/d in Doirani.

ET_O correlation obtained from the PM method and the other four methods

Linear correlation coefficients obtained between the PM-ET_O results as a function of the ET_O results computed by the other four methods, respectively, as well as the coefficients of determinations (R^2) are presented in Table 1. The equation type used was of the form: y = ax, as graph-lines were forced to pass through origin of the two axes.

Although this correlation is highly significant with R^2 values bigger than 0.85 for all sites and methods investigated, differences among the two ET_O values calculated by the PM method compared to the PT and FAO 24 CP methods, respectively, are large, as illustrated by the a values (very different from 1: the average a values were 0.733 with a coefficient of variation (CV) of 14.3 % for the PM(FAO 24 CP), and 0.751 with a CV of 11.6 % for the PM(PT) correlation). For the PM versus the two temperature-based methods correlation, differences in ET_O are smaller (a much closer to 1: the averaged *a* value was 0.862 with a CV of 7.2 for the H method, and 1.084 with a CV of 6.1% for the TH method). The close results performed by the PM and H methods are also shown by the R^2-values that were 0.986 averaged over all sites with a CV of 0.8 %, while for the other three types of correlation the average R^2 was 0.971 with a CV of 2.0 % for the PM(FAO 24 CP) one, 0.976 with a CV of 1.7 % for the PM(PT) one, and 0.933 with a CV of 4.3 % for the PM(TH) correlation. This finding is consistent with the data reported by Jensen *et al.*[10] for all methods applied, and Hargreaves [7] for the Hargreaves method.

Based on these findings the FAO 24 CP-ET_O/PM-ET_O, H-ET_O/PM-ET_O, TH-ET_O/PM-ET_O and PT- ET_O/PM-ET_O ratios were then calculated and illustrated in Table 2. For the PT/PM case this ratio is highly variable during the year with a maximum of 1.38 to 1.6 in period April-June for the Sindos-based *Rs* sites, and 1.14 in May for Thessaloniki, decreasing during the winter time to values specific for each site. Averaged over the May-September period this ratio varies from 1.1 in Thessaloniki and 1.25 in Sindos to 1.39-1.46 for the other sites, whereas over the whole year the ratio attains 0.96 in Thessaloniki and 1.02 in Sindos to 1.25-1.42 in the other sites. For these reasons the PT method

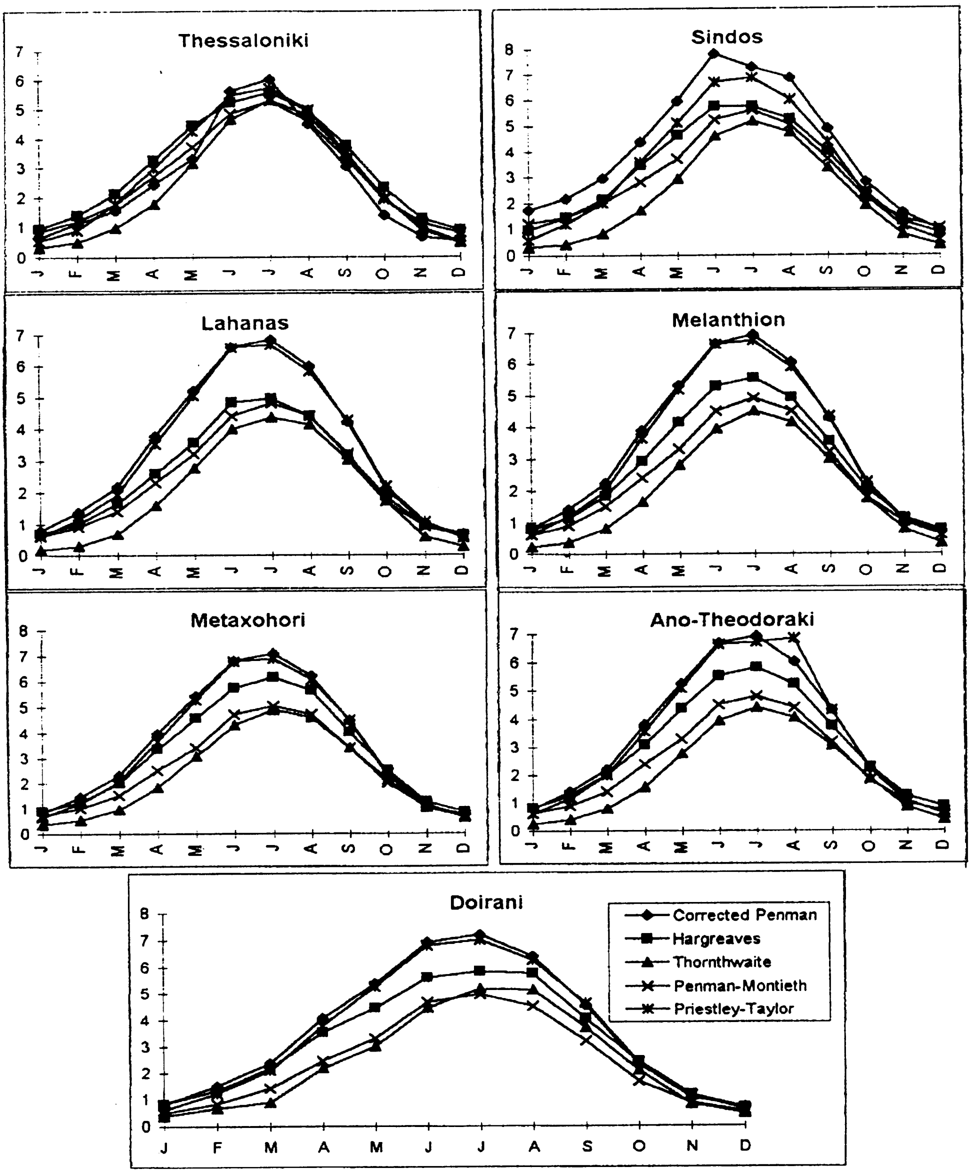

Fig. 1. Dynamics of ET_o values (mm/d) calculated by 5 methods in 7 sites within the Gallikos watershed.

Table 1. Linear - correlation parameters obtained between the ET_0 Penman-Monteith (PM) standard method results and the other ET_0 estimating methods results, respectively, for every site studied

Site	Correlated methods	Coefficient of x	R^2
Thessaloniki	PM (FAO 24 CP)	0.969	0.93
	PM (H)	0.899	0.99
	PM (TH)	1.042	0.91
	PM (PT)	0.920	0.98
Sindos	PM (FAO 24 CP)	0.708	0.97
	PM (H)	0.920	0.97
	PM (TH)	1.150	0.85
	PM (PT)	0.820	0.94
Lahanas	PM (FAO 24 CP)	0.689	0.98
	PM (H)	0.946	0.99
	PM (TH)	1.114	0.94
	PM (PT)	0.706	0.98
Melanthion	PM (FAO 24 CP)	0.695	0.98
	PM (H)	0.865	0.99
	PM (TH)	1.129	0.96
	PM (PT)	0.712	0.98
Metaxohori	PM (FAO 24 CP)	0.708	0.97
	PM (H)	0.809	0.99
	PM (TH)	1.062	0.96
	PM (PT)	0.726	0.98
Ano-Theodoraki	PM (FAO 24 CP)	0.691	0.98
	PM (H)	0.811	0.99
	PM (TH)	1.127	0.95
	PM (PT)	0.686	0.98
Doirani	PM (FAO 24 CP)	0.670	0.99
	PM (H)	0.784	0.98
	PM (TH)	0.961	0.96
	PM (PT)	0.687	0.99

needs to be calibrated versus lysimetric data in this region in order to be used in ET_O calculations.

The FAO 24 CP/PM ratio presented high values (1.41-1.48) for all sites, except Thessaloniki (1.03) over the May-September period, and 1.38-1.50 for the whole year in the same locations. Larger ET_O values calculated by the FAO 24 CP method that overestimated by about 10% the PM ET_O values were previously reported for a neighbour watershed by Panoras and Mavroudis [12].

For the H/PM case (Table 2), the ratio is more constant, ranging during period May-September from 1.05 to 1.15 (averaged values) in Thessaloniki, Sindos, Lahanas and Melanthion, and 1.22 to 1.25 in Metaxohori, Ano-Theodoraki and Doirani. For the whole year this ratio ranged from 1.03 to 1.19 in the former mentioned group of stations and 1.24 to 1.40 in the second one.

The TH/PM ratio variation among sites was the smallest, and ranged from 0.89 to 1.04 for period May-September and from 0.77 to 1.0 for the whole year.

Averaged over all sites within the Gallikos watershed for the irrigation season and the whole year, respectively, this ratio was 1.38 and 1.36 in the FAO 24 CP/PM case,1.16 and 1.20 for the H/PM case, 0.94 and 0.86 for the TH/PM case, and 1.36 and 1.22 for the PT/PM case.

T a b l e 2. Ratios between the ET_o methods and the Penman-Monteith standard method at each site studied and month (J-January, F-February, ..., D-December)

Site	Method	J	F	M	A	M	J	J	A	S	O	N	D	M-S	Yearly
Thessaloniki	Corrected Penman	0.77	0.92	0.88	0.90	0.89	1.16	1.14	0.98	0.91	0.73	0.58	0.65	1.03	0.96
	Hargreaves	1.13	1.16	1.20	1.20	1.20	1.08	1.05	1.08	1.13	1.20	1.13	1.11	1.11	1.14
	Thornthwaite	0.37	0.41	0.54	0.66	0.84	0.95	1.01	1.05	1.04	1.04	0.79	0.58	0.98	0.88
	Priestley-Taylor	0.65	0.74	1.02	1.10	1.14	1.13	1.08	1.08	1.06	1.01	0.86	0.65	1.10	0.96
Sindos	Corrected Penman	1.43	1.52	1.48	1.56	1.61	1.49	1.30	1.36	1.32	1.27	1.15	0.91	1.41	1.40
	Hargreaves	0.79	1.00	1.08	1.23	1.25	1.10	1.03	1.04	1.08	1.08	0.90	0.83	1.10	1.03
	Thornthwaite	0.23	0.27	0.40	0.61	0.79	0.88	0.92	0.94	0.91	0.86	0.56	0.36	0.89	0.77
	Priestley-Taylor	0.48	0.83	1.00	1.28	1.38	1.27	1.22	1.19	1.18	1.03	0.79	0.55	1.25	1.02
Lahanas	Corrected Penman	1.28	1.51	1.54	1.63	1.63	1.50	1.43	1.36	1.32	1.25	1.08	1.12	1.44	1.43
	Hargreaves	1.13	1.10	1.19	1.13	1.11	1.10	1.03	1.00	0.99	1.09	1.03	1.07	1.05	1.08
	Thornthwaite	0.28	0.31	0.47	0.68	0.86	0.90	0.91	0.94	0.94	1.01	0.62	0.43	0.91	0.83
	Priestley-Taylor	1.02	1.26	1.38	1.53	1.58	1.49	1.39	1.32	1.33	1.29	1.17	0.88	1.42	1.30
Melanthion	Corrected Penman	1.32	1.57	1.49	1.62	1.61	1.48	1.42	1.35	1.34	1.22	1.03	1.15	1.43	1.42
	Hargreaves	1.30	1.27	1.23	1.22	1.26	1.17	1.13	1.10	1.10	1.14	1.12	1.25	1.15	1.19
	Thornthwaite	0.35	0.40	0.53	0.69	0.85	0.88	0.92	0.92	0.93	0.97	0.77	0.57	0.90	0.83
	Priestley-Taylor	1.03	1.30	1.34	1.51	1.57	1.47	1.37	1.31	1.35	1.26	1.08	0.97	1.42	1.30
Metaxohori	Corrected Penman	1.19	1.48	1.49	1.58	1.59	1.44	1.41	1.32	1.31	1.15	0.96	1.04	1.41	1.38
	Hargreaves	1.26	1.26	1.31	1.34	1.34	1.22	1.22	1.20	1.19	1.25	1.15	1.20	1.23	1.24
	Thornthwaite	0.51	0.52	0.62	0.73	0.90	0.91	0.97	0.98	1.01	1.07	0.95	0.94	0.95	0.90
	Priestley-Taylor	0.93	1.22	1.34	1.48	1.55	1.44	1.36	1.29	1.32	1.19	1.04	0.87	1.39	1.25

Table 2. Continuation

Site	Method	J	F	M	A	M	J	J	A	S	O	N	D	M-S	Yearly
Ano-Theodoraki	Corrected Penman	1.32	1.57	1.59	1.59	1.59	1.48	1.44	1.37	1.35	1.22	1.02	1.00	1.44	1.42
	Hargreaves	1.38													
	Thornthwaite	0.42													
	Priestley-Taylor	1.													
Doirani	Corrected Penman	1.69	1.81	1.68	1.68	1.64	1.48	1.46	1.42	1.42	1.38	1.21	1.40	1.48	1.50
	Hargreaves	1.71	1.63	1.55	1.46	1.35	1.20	1.18	1.28	1.27	1.46	1.36	1.36	1.25	1.40
	Thornthwaite	0.75	0.80	0.63	0.89	0.91	0.96	1.05	1.14	1.16	1.25	0.93	0.88	1.04	1.00
	Priestley-Taylor	1.25	1.47	1.48	1.56	1.60	1.46	1.42	1.39	1.45	1.45	1.32	1.16	1.46	1.42

For the reasons shown, i.e., the close ratio values discussed above between the ET_O-PM and the temperature-based methods, as well as for their strong correlation and simplicity in calculation, it is suggested here that the ET_O-H and ET_O-TH methods be recommended for practical use in this area.

Spatial distribution of ET_O values calculated by the H method

Over the entire Gallikos watershed the ET_O values calculated through the H method during period May-September are illustrated in Fig 2. As a general rule ET_O isolines are traced almost north-south for all months. An increase in ET_O values is thus noticed from the eastern to the western part of the Gallikos watershed, associated with a general decrease in altitude in the same direction and an increase in distance from the sea; maximum ET_O values were recorded for the Metaxohori neighbouring area.

For instance, in May ET_O ranged from 4.0 mm/d in the eastern part of the Gallikos watershed to 4.6 mm/d in Metaxohori and Sindos area. In June, ET_O decreased from less than 5.2 mm/d around Lahanas to 5.7 mm/d in the western part of the watershed. During the peak month, July, ET_O values ranged from 5.4 mm/d for the eastern part to 6.1 mm/d around the pole of maximum values in the Gallikos watershed, Metaxohori. In August, ET_O varied from 4.8 mm/d for the eastern watershed border to 5.6 mm/d in Metaxohori, showing the highest ET_O spatial variation, while in September ET_O increases from 3.5 mm/d in east to 4.0 mm/d in Metaxohori, showing now the lowest ET_O spatial variation.

Crop water requirements (CWR), crop coefficients (Kc) and irrigation water requirements (IWR) for 8 crops in the area studied

Crop water requirements

CWR for 8 more or less representative crops related to each site investigated within the Gallikos watershed during the period May-September for both individual months and as totals

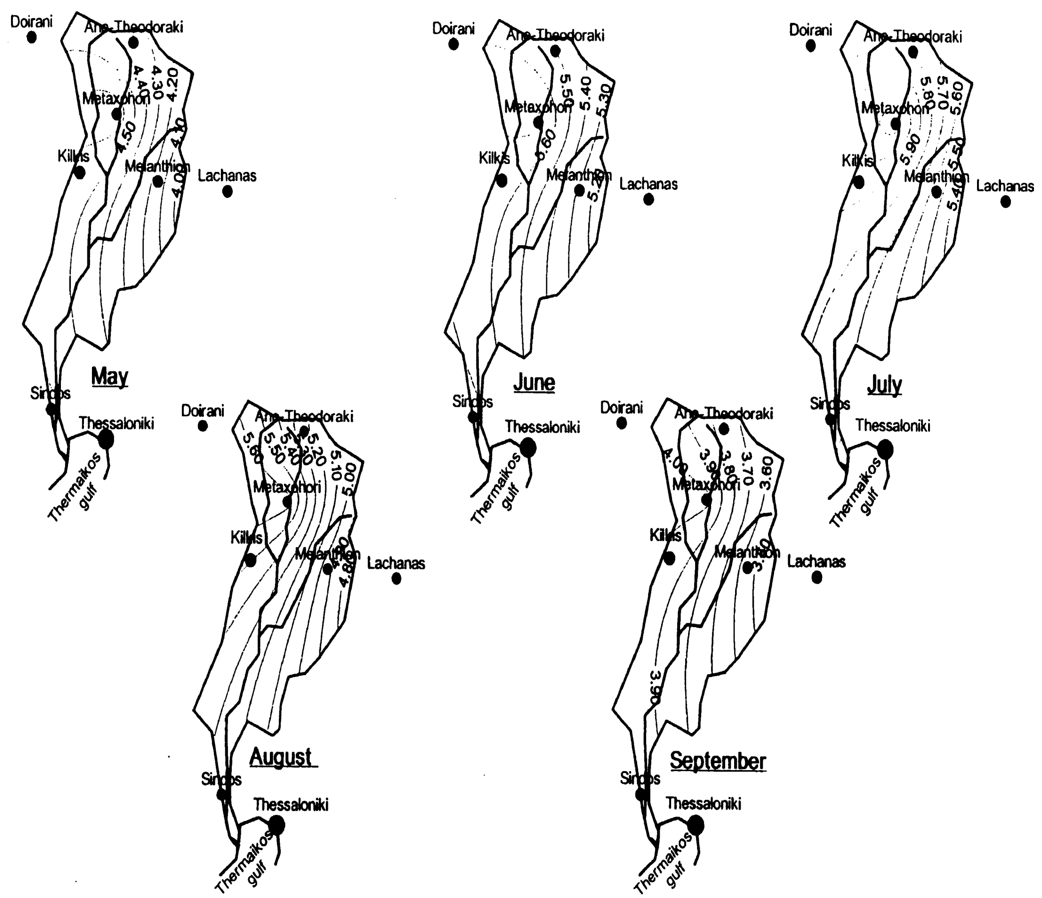

Fig. 2. Mean daily ET_o isoline values (mm/d) during the irrigation season in the Gallikos watershed.

are shown in Table 3. During the whole irrigation period the maximum CWR values for all crops were calculated for Sindos, followed by Doirani and Metaxohori. The difference between this finding and the maximum ET_O values for Metaxohori discussed in the previous subchapter is due to the spatial interference between adjacent sites. For the crops referred here, corn and cotton use almost the same water (rain + irrigation) amount during the irrigation period, around 450 mm in Thessaloniki and approximately 600 mm in the other sites, where as alfalfa, tobacco, sugarbeet and sunflower were grouped together with circa 550 mm in Thessaloniki area and 650-750 mm for the other sites. The other two crops, tomato and grape consume smaller amounts of water during the growing season, ranging from about 400 mm in Thessaloniki area to 500 mm within the other sites for tomato, and about 300 mm in Thessaloniki to 350 mm in the other sites for grape.

Crop coefficients

With the help of crop coefficients, Kc, CWR can be calculated. Table 4 provide Kc values for each site, crop and month for both the recommended ET_O method, i.e., the H method. For all months taken into account, June and July manifest the highest Kc values, most of them >1 (except for Thessaloniki), while May and September show the lowest Kc values. Among crops, sunflower had the highest Kc values, up to 1.5 in Sindos and Lahanas in June, but this value should be regarded with care as its Kc was

Table 3. Crop water requirements (mm/day) for 8 crops within the Gallikos watershed, 7 weather stations

Crop	May	June	July	Aug.	Sept.	Total
			Thessaloniki			
Corn	1.3	4.0	5.1	3.7	0.9	459.0
Cotton	1.1	3.1	5.1	4.1	1.5	453.5
Alfalfa	2.8	4.8	5.1	3.8	2.6	585.3
Tobacco	1.7	5.6	6.0	4.3		540.9
Tomato	1.4	4.1	5.1	1.7		377.9
Sugarbeet	1.5	4.5	5.1	3.8	2.5	533.1
Sunflower	2.6	6.2	5.4	2.3		505.4
Grape	1.0	2.0	3.0	2.0	1.1	277.8
			Sindos			
Corn	2.4	5.5	6.2	5.5	1.4	646.3
Cotton	1.9	4.4	6.1	6.2	2.3	641.0
Alfalfa	5.1	6.6	6.2	5.8	4.1	852.7
Tobacco	3.1	7.8	7.2	6.6		757.4
Tomato	2.5	5.7	6.2	2.6		521.0
Sugarbeet	2.7	6.2	6.2	5.8	4.0	762.7
Sunflower	4.8	8.6	6.6	3.4		714.7
Grape	1.8	2.7	3.6	3.1	1.7	396.9
			Lahanas			
Corn	2.1	4.7	5.8	4.9	1.2	572.7
Cotton	1.7	3.7	5.7	5.4	2.0	568.8
Alfalfa	4.4	5.6	5.8	5.1	3.6	751.5
Tobacco	2.7	6.6	6.8	5.8		670.3
Tomato	2.2	4.8	5.8	2.3		463.3
Sugarbeet	2.3	5.3	5.8	5.1	3.5	673.3
Sunflower	4.2	7.3	6.2	3.0		630.8
Grape	1.6	2.3	3.4	2.7	1.5	351.8
			Melanthion			
Corn	2.1	4.7	5.9	4.9	1.2	579.8
Cotton	1.7	3.7	5.8	5.5	2.1	576.0
Alfalfa	4.5	5.7	5.9	5.2	3.7	761.4
Tobacco	2.8	6.7	6.9	5.8		678.3
Tomato	2.2	4.9	5.9	2.3		468.9
Sugarbeet	2.4	5.3	5.9	5.2	3.5	681.9
Sunflower	4.2	7.3	6.2	3.0		638.4
Grape	1.6	2.3	3.5	2.7	1.5	356.4
			Metaxohori			
Corn	2.2	4.8	6.0	5.0	1.3	593.5
Cotton	1.7	3.8	6.0	5.6	2.1	590.1
Alfalfa	4.6	5.8	6.0	5.3	3.8	780.1
Tobacco	2.8	6.8	7.0	6.0		693.6
Tomato	2.3	5.0	6.0	2.4		479.2
Sugarbeet	2.4	5.4	6.0	5.3	3.7	698.9
Sunflower	4.3	7.5	6.4	3.1		652.5
Grape	1.6	2.4	3.5	2.8	1.6	365.1

Table 3. Continuation

Crop	May	June	July	August	September	Total
			Ano - Theodoraki			
Corn	2.1	4.7	5.9	4.9	1.2	578.2
Cotton	1.7	3.7	5.8	5.4	2.1	574.4
Alfalfa	4.5	5.7	5.9	5.1	3.7	759.3
Tobacco	2.7	6.7	6.9	5.8		676.3
Tomato	2.2	4.9	5.9	2.3		467.7
Sugarbeet	2.4	5.3	5.9	5.1	3.5	680.3
Sunflower	4.2	7.3	6.2	3.0		636.7
Grape	1.6	2.3	3.5	2.7	1.5	355.4
			Doirani			
Corn	2.2	4.9	6.1	5.2	1.3	603.1
Cotton	1.7	3.9	6.0	5.7	2.2	600.0
Alfalfa	4.6	5.9	6.1	5.4	3.8	791.1
Tobacco	2.8	6.9	7.1	6.1		704.9
Tomato	2.3	5.0	6.1	2.4		486.3
Sugarbeet	2.4	5.5	6.1	5.4	3.7	709.9
Sunflower	4.3	7.6	6.5	3.2		661.2
Grape	1.6	2.4	3.6	2.9	1.6	370.7

the only one built theoretically from the general estimation procedure described by Doorenbos and Pruitt [5].

Irrigation water requirements

IWR for each site, crop and month of inte- rest are presented in Table 5. Crop groups characterised for CWR remain also valid for this topic as rainfall is relatively constant in small areas. Most crops, except alfalfa only need small amounts of irrigation water in May; but care should be taken when accounting for sunflower values due to the aspects already mentioned.

The other three months: June, July and August are of great interest for irrigation due to the high values of IWR in this area. For all crops, except grape and cotton, the monthly recommended irrigation amount exceeds 100 mm in June, while in July IWR attains about 150 mm (again except grape that requires only 70-80 mm), even more for tobacco, that is consistent with the conclusions reported for similar climatic conditions by Panoras and Mavroudis [14]. In August IWR still remain rather high (100-150 mm) for many crops (corn, cotton, alfalfa, tobacco and sugarbeet, whilst for tomato, sunflower and grape IWR are small now (about 50 mm).

In September there is an abrupt decrease in IWR for most crops due to harvest approaching, except alfalfa and sugarbeet that still need about 50-100 mm, depending on site considered.

The monthly values presented above should be regarded as IWR for the medium climatic year. If shortage in water supply appears during the growing season in some years, then the irrigation water application performed under water stress conditions should follow special strategies developed for this situation.

CONCLUSIONS

From all five estimating reference evapotranspiration methods, the temperature-based methods yielded the closest ET_O values compared to the Penman-Monteith standard method, that recommended them for use in this area. Although the Hargreaves method has the simplest way of calculation, it produced the strongest correlated values to the Penman-Monteith method. For this reason the Hargreaves method was used to compute ET_O isolines in the Gallikos watershed.

Table 4. Crop coefficients for the Hargreaves Et_o method, 8 crops, 7 weather stations

Crop	May	June	July	Aug.	Sept.
			Thessaloniki		
Corn	0.30	0.76	0.92	0.74	0.23
Cotton	0.24	0.60	0.91	0.82	0.39
Alfalfa	0.63	0.91	0.92	0.77	0.68
Tobacco	0.39	1.07	1.07	0.87	
Tomato	0.31	0.78	0.92	0.35	
Sugarbeet	0.33	0.86	0.92	0.77	0.66
Sunflower	0.59	1.18	0.98	0.45	
Grape	0.22	0.38	0.54	0.41	0.28
			Sindos		
Corn	0.52	0.97	1.08	1.06	0.36
Cotton	0.41	0.76	1.06	1.17	0.59
Alfalfa	1.10	1.16	1.08	1.11	1.04
Tobacco	0.67	1.36	1.25	1.25	
Tomato	0.54	0.99	1.08	0.50	
Sugarbeet	0.58	1.09	1.08	1.11	1.01
Sunflower	1.03	1.50	1.14	0.65	
Grape	0.39	0.48	0.63	0.59	0.43
			Lahanas		
Corn	0.58	0.97	1.18	1.10	0.39
Cotton	0.47	0.76	1.16	1.23	0.64
Alfalfa	1.24	1.16	1.18	1.16	1.14
Tobacco	0.76	1.37	1.37	1.31	
Tomato	0.61	1.00	1.18	0.52	
Sugarbeet	0.66	1.09	1.18	1.16	1.10
Sunflower	1.17	1.50	1.25	0.68	
Grape	0.44	0.48	0.69	0.61	0.47
			Melanthion		
Corn	0.51	0.89	1.06	1.00	0.35
Cotton	0.41	0.71	1.05	1.11	0.58
Alfalfa	1.09	1.07	1.06	1.04	1.03
Tobacco	0.66	1.26	1.24	1.18	
Tomato	0.54	0.92	1.06	0.47	
Sugarbeet	0.57	1.01	1.06	1.04	1.00
Sunflower	1.02	1.39	1.13	0.61	
Grape	0.38	0.44	0.63	0.55	0.43
			Metaxohori		
Corn	0.47	0.84	0.98	0.89	0.32
Cotton	0.38	0.66	0.97	0.99	0.53
Alfalfa	1.01	1.01	0.98	0.94	0.94
Tobacco	0.62	1.18	1.14	1.06	
Tomato	0.50	0.87	0.98	0.42	
Sugarbeet	0.53	0.95	0.98	0.94	0.91
Sunflower	0.95	1.30	1.04	0.55	
Grape	0.36	0.41	0.58	0.50	0.39

Table 4. Continuation

Crop	May	June	July	Aug.	Sept.
			Ano - Theodoraki		
Corn	0.48	0.86	1.02	0.93	0.33
Cotton	0.39	0.68	1.00	1.04	0.55
Alfalfa	1.02	1.03	1.02	0.98	0.98
Tobacco	0.63	1.21	1.18	1.11	
Tomato	0.51	0.89	1.02	0.44	
Sugarbeet	0.54	0.97	1.02	0.98	0.94
Sunflower	0.96	1.33	1.08	0.58	
Grape	0.36	0.42	0.60	0.52	0.40
			Doirani		
Corn	0.48	0.88	1.05	0.90	0.33
Cotton	0.39	0.69	1.04	1.00	0.54
Alfalfa	1.03	1.05	1.05	0.94	0.95
Tobacco	0.63	1.24	1.23	1.07	
Tomato	0.51	0.90	1.05	0.42	
Sugarbeet	0.54	0.99	1.05	0.94	0.92
Sunflower	0.97	1.36	1.12	0.56	
Grape	0.36	0.43	0.62	0.50	0.39

Table 5. Irrigation water requirements (mm) for 8 crops within the Gallikos watershed, 7 weather stations

Crop	May	June	July	Aug.	Sept.	Total
			Thessaloniki			
Corn	0.0	88.6	134.9	87.3	5.6	316.4
Cotton	0.0	63.4	133.0	99.8	22.8	319.1
Alfalfa	41.9	112.2	134.9	92.9	56.5	438.3
Tobacco	8.0	137.5	161.0	108.2		414.8
Tomato	0.0	92.0	134.9	27.1		254.1
Sugarbeet	0.8	103.8	134.9	92.9	53.7	386.1
Sunflower	36.7	154.4	144.2	43.9		379.3
Grape	0.0	27.9	69.6	36.9	11.0	145.5
			Sindos			
Corn	29.9	135.2	171.3	151.1	15.9	503.5
Cotton	15.1	100.1	169.1	170.2	43.7	498.2
Alfalfa	113.1	168.0	171.3	159.6	97.9	709.9
Tobacco	52.1	203.2	202.9	182.9		641.1
Tomato	33.6	139.9	171.3	59.9		404.8
Sugarbeet	39.2	156.3	171.3	159.6	93.5	619.9
Sunflower	103.8	226.6	182.6	85.4		598.4
Grape	11.4	50.9	92.3	74.8	24.7	254.1

Table 5. Continuation

Crop	May	June	July	Aug.	Sept.	Total
			Lahanas			
Corn	0.0	92.1	131.6	104.0	11.3	339.0
Cotton	0.0	62.4	129.5	120.7	35.4	348.0
Alfalfa	71.3	119.9	131.6	111.4	82.3	516.6
Tobacco	18.1	149.6	161.3	131.9		460.9
Tomato	2.0	96.1	131.6	24.2		253.9
Sugarbeet	6.8	110.0	131.6	111.4	78.5	438.4
Sunflower	63.2	169.5	142.2	46.4		421.4
Grape	0.0	20.7	57.4	37.2	18.9	134.2
			Melanthion			
Corn	13.5	92.6	146.3	117.3	7.1	376.7
Cotton	0.3	62.7	144.1	134.2	31.6	372.9
Alfalfa	87.4	120.5	146.3	124.8	79.3	558.3
Tobacco	33.2	150.4	176.4	145.5		505.5
Tomato	16.8	96.6	146.3	36.5		296.2
Sugarbeet	21.7	110.5	146.3	124.8	75.4	478.8
Sunflower	79.2	170.4	157.0	59.1		465.7
Grape	0.0	20.8	71.0	49.7	14.8	156.2
			Metaxohori			
Corn	19.5	95.7	148.6	114.0	10.2	388.1
Cotton	6.1	65.2	146.4	131.4	35.6	384.7
Alfalfa	95.0	124.2	148.6	121.7	85.1	574.7
Tobacco	39.7	154.8	179.4	142.9		516.8
Tomato	22.9	99.8	148.6	31.1		302.4
Sugarbeet	27.9	114.0	148.6	121.7	81.1	493.4
Sunflower	86.6	175.2	159.6	54.2		475.6
Grape	2.8	22.4	71.7	44.6	18.2	159.7
			Ano - Theodoraki			
Corn	18.2	99.2	154.6	118.8	9.6	400.4
Cotton	5.2	69.2	152.4	135.6	34.2	396.6
Alfalfa	91.4	127.2	154.6	126.3	82.1	581.5
Tobacco	37.7	157.2	184.6	146.8		526.4
Tomato	21.4	103.2	154.6	38.6		317.8
Sugarbeet	26.3	117.2	154.6	126.3	78.2	502.6
Sunflower	83.3	177.2	165.3	61.0		486.8
Grape	1.9	27.2	79.5	51.7	17.4	177.6
			Doirani			
Corn	33.8	99.9	146.3	134.0	30.1	444.1
Cotton	20.5	68.8	144.1	151.8	55.9	441.0
Alfalfa	108.8	128.9	146.3	141.9	106.0	632.0
Tobacco	53.8	160.0	177.6	163.7		555.1
Tomato	37.1	104.0	146.3	49.0		336.4
Sugarbeet	42.1	118.5	146.3	141.9	102.0	550.9
Sunflower	100.5	180.7	157.5	72.7		511.4
Grape	17.1	25.2	68.2	62.8	38.2	211.6

Reference evapotranspiration isolines as yielded by the Hargreaves method showed a characteristic pattern, by decreasing from the eastern part to the western part within the Gallikos watershed. Crop water requirements as well as irrigation water requirements divided crops into more groups. These crops can be an alternative for the present situation characterised mainly by wheat. For shortage in irrigation water supply special scenarios not developed here should be followed.

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