European Water 13/14: 3-13, 2006.

Mapping Crop Evapotranspiration and Total Crop Water Requirements Estimation in Central Greece

M. Sakellariou-Makrantonaki, I. N. Vagenas
University of Thessaly - Department of Agriculture, Crop Production and Rural Environment
Fitokou Street, 38446 Nea Ionia, Volos
email msak@uth.gr

Abstract: The aim of this study is to map the reference crop evapotranspiration and rainfall and with the aid of these maps to estimate the total irrigation crop water requirements in central Greece (Prefectures of Larissa and Magnesia) irrigated both by private and public boreholes and by surface waters during the irrigation period of the year 2001 by using FAO Penman-Monteith method. The mean daily reference crop evapotranspiration for each month and each of the 54 Municipalities of the two Prefectures was estimated, by using meteorological data for a period of 22 years (1980-2001). Crop evapotranspiration and net water requirements were computed for each crop in the Municipalities of the Prefectures for the whole irrigation period. Finally, the total irrigation water requirements of crops during the irrigation period of the year 2001 for the 147,299 hectares of irrigated land of the region were estimated 698,000,000m^3 with average 4,739m^3/hectare.

Key words: mapping, central Greece, evapotranspiration, Penman-Monteith , crop water requirements

1. INTRODUCTION

The water, as natural resource, constitutes a condition of life and essential infrastructure for development and culture for each country. Particularly in a country like Greece whose economy relies at a big percentage on Agriculture, the importance of water in its development is even bigger. The intensification of Agriculture, the big increase of irrigated area as well as the need for more competitive products, contribute to the continuously increasing demand in water for irrigation. Irrigation absorbs the biggest percentage (83.6%) (SRTS, 1980) of water consumption in Greece. Thus nowadays, it is imperative to estimate the amount of water required for each type of crop accurately with modern methods according to which it is estimated that there can be a 30% economy in irrigation water in relation to the previous methods of estimation (Papazaferiou, 2000).

A few researchers have dealt with the crop water requirements of the Thessalian plain which is the biggest agricultural region with the more intensive irrigation in Greece. Some of them are Kougoulos (1979), Patmanidis (1979) and the former Ministry of Public Work, now Ministry of Environment Planning and Public Works (Preliminary study that was worked out by Offices ETEM – "Eypalinos", 1960 and preliminary study of ELECTROWATT on the exploitation of water potential of Thessaly, 1968). Patmanidis (1979) calculated the consumption of various crops per hectare with the method of Blaney-Criddle in 7,000m^3, quantity which is high enough according to Patmanidis (1979) and Hatzilakos (1979). The last study of M. Sakellariou-Makrantonaki (1996) titled "Total crop water requirements of the Thessalian plain", calculated the total requirements of crops on average at the irrigation period of the year 1994 with the modified Penman method in 4,800m^3 per hectare, including a percentage of losses around 20%.

Extensive studies that were carried out by the FAO (Food and Agriculture Organization of the United Nations), by the Commission on the Irrigation Water Requirements of the American Society of Civil Engineers (ASCE) and by the European Institutes of Research, that collaborated under the responsibility of the European Community, compared the results of various methods with measurements from lysimeters in localities with different climatic conditions. The results of the studies showed that only the method of Penman-Monteith was relatively precise under all the climatic treaties (dry and humid) (Pereira et al., 1989, Smith et al., 1991, Allen et al., 1994, Ministry of Agriculture, 2000). Also Papazaferiou (1999), after research he carried out in 1996 comparing various methods of calculation of reference evapotranspiration, showed that all the methods overestimated it and in particular, reference evapotranspiration with the use of modified method of Penman was found at 28.5% higher than the one that was found with the FAO Penman-Monteith method. The use of this method is also widespread in the modern greenhouses in both research and practice (Kittas et al., 1999, Katsoulas et al., 2001).

The aim of this study is to map the reference crop evapotranspiration and rainfall and with the aid of these maps to estimate the total irrigation crop water requirements in the Prefectures of Larissa and Magnesia by using the FAO Penman-Monteith method that is considered at the moment the most precise under all the climatic conditions. Historical climatic data of 22 years was used from all the meteorological stations of the two Prefectures as well as from stations situated on the Prefecture of Larissa and Magnesia. The estimation of crop water requirements was done for each Municipality, which is the smallest possible partial division of the Prefectures.

2. THEORY

The Penman – Monteith equation (Monteith, 1981, Allen et al, 1998) which resulted from the combination of the energy balance and the mass transfer method and the use of two resistance factors, aerodynamic resistance and the (bulk) surface resistance, has the following form (Eq. 2.1):

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \dfrac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \dfrac{r_s}{r_a}\right)} \tag{2.1}$$

where λET is the latent heat flux (MJ m^{-2} day^{-1}), R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux (MJ m^{-2} day^{-1}), (e_s - e_a) represents the vapour pressure deficit of the air (kPa), e_s the mean saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), ρ_α is the mean air density at constant pressure (kg m^{-3}), c_p is the specific heat of moist air at constant pressure (MJ kg^{-1} $^oC^{-1}$), Δ represents the slope of the saturation vapour pressure and temperature relationship (slope vapour pressure curve) (kPa $^oC^{-1}$), γ is the psychrometric constant (kPa $^oC^{-1}$), and r_s and r_a are the (bulk) surface and aerodynamic resistances (s m^{-1}), respectively.

The transfer of heat and water vapour from the evaporating surface into the air above the canopy is determined by the aerodynamic resistance (Eq. 2.2):

$$r_a = \frac{\ln\left(\dfrac{z_m - d}{z_{om}}\right)\ln\left(\dfrac{z_h - d}{z_{oh}}\right)}{k^2 u_z} \tag{2.2}$$

where
ra, aerodynamic resistance [s m-1],
zm, height of wind measurements [m],
zh, height of humidity measurements [m],
d, zero plane displacement height [m],
zom, roughness length governing momentum transfer [m],
zoh, roughness length governing transfer of heat and vapour [m],
k, von Karman's constant, 0.41 [-],

uz, wind speed at height z [m s-1].

The 'bulk' surface resistance describes the resistance of vapour flow through the transpiring crop and evaporating soil surface. Where vegetation does not completely cover the soil, the resistance factor should indeed include the effects of the evaporation from the soil surface. If the crop is not transpiring at a potential rate, the resistance depends also on the water status of the vegetation. An acceptable approximation to a much more complex relation of the surface resistance of dense full cover vegetation is (Eq. 2.3):

$$r_s = \frac{r_I}{LAI_{active}} \tag{2.3}$$

where

r_s, (bulk) surface resistance [s m^{-1}],

r_l, bulk stomatal resistance of the well-illuminated leaf [s m^{-1}],

LAI_{active}, active (sunlit) leaf area index [m^2 (leaf area) m^{-2} (soil surface)].

The consultation of experts and researchers which was organized by FAO in May 1990, in collaboration with the International Commission for Irrigation and Drainage and with the World Meteorological Organization, suggested the FAO Penman-Monteith equation by defining the reference crop as a hypothetical crop with an assumed height (h) of 0.12m having a surface resistance of $r_s = 70s\ m^{-1}$ and an albedo of 0.23, closely resembling the evaporation of an extensive surface of green grass of uniform height, actively growing, completely shading the ground and adequately watered.

The term r_s = 70s m^{-1} resulted considering that $LAIactive = 0.5\ LAI$ (Monteith, 1965 and Sceicz and Long, 1969) where $LAI = 24 \cdot h$ (Allen et al., 1989,1994) and r_I = 100s m^{-1}.

Also, considering that the measurements of wind speed, of temperature and humidity have been conducted at 2m height and that d = 2/3 of h (Plate, 1971 and Monteith, 1981), $z_{om} = 0.123\ h$ (Brutsaert, 1975) and $z_{oh} = 0.1\ z_{om}$ (Brutsaert, 1975), the aerodynamic resistance (Equation 2.2) results to be equal to $r_a = 208/u_2$, where u_2 is the speed of wind in m s^{-1} in 2m.

Therefore, the resistance term of Equation (2.1) becomes (Eq. 2.4):

$$(1 + r_s/r_a) = (1 + 0.34\ u_2) \tag{2.4}$$

(R_n – G) is the energy available per unit area and expressed in MJ m^{-2} day^{-1}. To convert the energy units for radiation to equivalent water depths (mm) the latent heat of vaporization, λ, is used as a conversion factor. As we know for water evaporation of 1mm per day it is required energy 2.45MJ m^{-2} day^{-1}.

The specific heat c_p is given by the Equation 2.5:

$$c_p = \frac{\gamma \cdot \varepsilon \cdot \lambda}{P} \tag{2.5}$$

while the mean air density ρ_α at constant pressure according to the ideal gas law is given by the Equation 2.6:

$$\rho_\alpha = \frac{P}{T_{KV} R} \tag{2.6}$$

where T_{KV} is the virtual temperature, which may be substituted by

$$T_{KV} = 1.01(T + 273)$$

Thus the term $\frac{c_p \rho_a}{r_a}$ of the Equation (2.1) becomes (Eq. 2.7):

$$\frac{c_p \rho_a}{r_a} = \frac{\gamma \cdot \varepsilon \cdot \lambda}{1.01(\mathrm{T}+273)R(208)} u_2 \text{ (MJ m}^{-2}\,{}^{o}\text{C}^{-1}\text{ day}^{-1}\text{)} \qquad (2.7)$$

where
ε, the ratio molecular weight of water vapour/dry air = 0.622,
R, specific gas constant = 0.287kJ kg^{-1} K^{-1},
T, the mean daily temperature of air at 2 m height (^{o}C) and
P, atmospheric pressure (kPa).

Therefore

$$\frac{c_p \rho_a}{r_a} = 86{,}400 \frac{\gamma(0.622)\lambda}{1.01(\mathrm{T}+273)(0.287)(208)} u_2 \text{ (MJ m-2 oC-1 day-1)}$$

or, when divided by λ (λ = 2.45) it results,

$$\frac{c_p \rho_a}{\lambda \cdot r_a} \approx \gamma \frac{900}{\mathrm{T}+273} u_2 \text{ (mm }^{o}\text{C day}^{-1}\text{)}$$

Thus, from the original Penman-Monteith Equation (2.1) for reference crop as it was defined above, the FAO Penman-Monteith method to estimate ET_o can be derived (Eq. 2.8):

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{\mathrm{T}+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (2.8)$$

where
ET_o, reference evapotranspiration [mm day^{-1}],
T, mean daily air temperature at 2 m height [°C],
u_2, wind speed at 2m height [m s^{-1}].

3. METHODOLOGY

For the calculation of the mean daily reference crop evapotranspiration for each month the meteorological data of 22 years (1980–2001) from 7 meteorological stations (National Weather Bureau, Ministry of Rural Development and Food, Cotton Organization etc.) of the Prefectures Larissa and Magnesia were used (Table 1).

In Table 1, T_{max} and T_{min} indicate the average maximum and minimum monthly temperature, RH_{mean} the average monthly relative humidity, n the average monthly actual duration of bright sunshine and u_d the average monthly wind speeds. The symbols (+) or (-) inform about the existence or non-existence of the climatic data in the stations.

By these climatic data, the mean daily reference crop evapotranspiration for each month of the irrigation period (April up to October) ETo was calculated in the positions of the 7 meteorological stations.

In an older study (Sakellariou-Makrantonaki, M. S, 1996) in which the average monthly values of climatic data of 22 years of the stations of Larissa, Livadi, Skopia, and Sotirio with the use of modified method of Penman was used, the reference crop evapotranspiration for the period from

May up to September was found 8,340mm per hectare. In the present study using the average monthly values of climatic data of 22 years from the same stations of the Prefecture of Larissa and for the same irrigation period, the reference crop evapotranspiration by FAO Penman-Monteith method was found 7,040mm per hectare, that is to say lower by 18.5%. This is a verification of the overestimation of the modified method of Penman.

Table 1. The meteorological stations of the Prefectures of Larissa and Magnesia.

Station	Prefecture	elevation	latitude	T_{max}	T_{min}	RH_{mean}	n	u_d
1 Larissa	Larissa	73	39° 38′	+	+	+	+	+
2 Livadi	Larissa	1183	40° 08′	+	+	+	+	+
3 Skopia	Larissa	580	39° 09′	+	+	+	+	+
4 Sotirio	Larissa	51	39° 30′	+	+	+	+	+
5 Farsala*	Larissa	148	39° 23′	+	+	+	-	-
6 Kato Lehonia**	Magnesia	70	39° 20′	+	+	+	-	-
7 Nea Anchialos	Magnesia	15	39° 15′	+	+	+	+	+

*The missing climatic data of the station was supplemented by the equivalents of the station of Larissa from which it abstains 32Km and

**The missing climatic data of the station was supplemented by the equivalents of the station of New Anchialos which is 21,6Km away, taking into account that:

(i) the size of the region is small;

(ii) the air masses governing rainfall and cloudiness are nearly identical within parts of the region and

(iii) the physiography of the region is almost homogenous.

Using the interpolation method Kriging-Linear (software SURFER16), an interpolation took place between the values of the mean daily reference crop evapotranspiration that were found in the positions of the stations. So the isoevapotranspiration curves for the whole irrigation period were obtained. Indicatively the isoevapotranspiration curves of the months May, June, July and August are presented in this paper (Figures 1, 2, 3 and 4). The map that was used as background, on which the curves were adapted in the software SURFER16, was processed in the software COREL Photo-paint8.

Then the mean daily reference crop evapotranspiration for each month and each Municipality of the Prefectures was estimated. This was achieved by means of the use of the figures of isoevapotranspiration curves and the application of integrals of area for each Municipality in them. More concretely, with the use of the software SURFER16 in each figure, after the limits of each Municipality were given (files with the limits of each Municipality were created), the volume of the evapotranspiration and the area encompassed in the limits of each Municipality were calculated with numerical methods (trapezium law, Simpson and Simpson 3/8). Usually, because the step that was given for these calculations was the smallest possible, there weren’t any divergences between the results of these three methods. In the cases in which certain small divergences appeared, the values that resulted from the average of the results of the three methods were used. Thus, dividing the volume of the evapotranspiration with the area, the mean daily reference crop evapotranspiration for each month and each Municipality was found.

Meteorological data of 22 years (1980–2001) from 25 stations of rainfall were used in order to calculate the mean monthly rainfall. In the same way, the calculation of mean monthly rainfall P of each month for each Municipality of the Prefectures was also done. That is to say that initially the mean monthly rainfall in the positions of the 25 rainfall stations was found and the isohyetial curves resulted with linear interpolation between this values (indicatively figures 5 and 6 are presented).

With the use of these curves the mean monthly rainfall was calculated and from this, with a method of USDA (Soil Conservation Service), the mean monthly effective rainfall P_e of each month for each Municipality of two Prefectures was computed.

Using the Equation (3.1) the crop evapotranspiration for each crop ET_c was found in the Municipalities of the two Prefectures for the whole irrigation period, with the aid of the mean crop coefficients at stage of growth, Kc, as they are given by Allen et al. (1996) (Table 2) and what was determined by Papazaferiou (1999) in the climatic conditions of Greece (Table 3).

$$ET_c = ET_o Kc \quad (3.1)$$

where ET_o is the reference crop evapotranspiration and Kc is the mean crop coefficients at stage of growth.

Table 2. Crop coefficients at stage of growth (SG), Kc, for crops that develop in semihumid climate, for use with the combined FAO Penman-Monteith method, as they are given by Allen et al. (1996).

Crop	1st SG	Kc	2nd SG	Kc	3rd SG	Kc	4th SG	Kc	sum	date of seeding	date of harvest
cotton	35	0,35	65	0,35~1,15	50	1,15	35	1,15~0,60	185	20/4	22/10
sugar beets	30	0,35	45	0,35~1,20	90	1,20	50	1,20~0,70	215	1/3	2/10
maize	25	0,30	40	0,30~1,20	60	1,20	30	1,20~0,35	155	15/4	17/9
vines	30	0,30	60	0,30~0,75	40	0,75	80	0,75~0,45	210	17/2	15/9
trees	25	0,55	80	0,55~0,85	85	0,85	70	0,85~0,70	260	28/1	15/10
cucumber family	25	0,50	35	0,50~1,00	40	1,00	20	1,00~0,75	120	5/4	3/8
vegetables	25	0,60	35	0,60~1,15	40	1,15	20	1,15~0,70	120	24/4	22/8
cereals	20	0,30	120	0,30~1,15	50	1,15	20	1,15~0,25	210	20/11	18/6
tobacco	15	0,50	25	0,50~1,15	55	1,15	20	1,15~0,80	115	5/5	28/8
alfalfa 1st cut	10	0,40	30	0,40~1,20	25	1,20	10	1,20~1,15	75	18/2	4/5
alfalfa 2nd cut	5	>>	16	>>	11	>>	5	>>	37	4/5	10/6
alfalfa 3rd cut	5	>>	10	>>	10	>>	5	>>	30	10/6	10/7
alfalfa 4th cut	5	>>	11	>>	10	>>	5	>>	31	10/7	10/8
alfalfa 5th cut	5	>>	15	>>	11	>>	5	>>	36	10/8	15/9
alfalfa 6th cut	5	>>	15	>>	10	>>	5	>>	35	15/9	20/10

Table 3. Crop coefficients at stage of growth (SG), Kc, adapted in the climatic conditions of Greece, as they were defined by Papazaferiou (1999) for use with the combined FAO Penman-Monteith method.

Crop	1st SG	Kc	2nd SG	Kc	3rd SG	Kc	4th SG	Kc	sum	date of seeding	date of harvest
cotton	35	0,45	65	0,45~1,05	50	1,05	35	1,05~0,60	185	20/4	22/10
sugar beets	30	0,45	45	0,45~1,00	90	1,00	50	1,00~0,50	215	1/3	2/10
maize	25	0,50	40	0,50~1,05	60	1,05	30	1,05~0,60	155	15/4	17/9
vines	90	0,40	45	0,40~0,60	60	0,60	15	0,60~0,45	210	17/2	15/9
trees	25	0,55	80	0,55~0,85	85	0,85	70	0,85~0,70	260	28/1	15/10

The net water requirements of crops were calculated by the Equation (3.2)

$$I_n = ET_c - \left(P_e + G_w + SM\right) \quad (3.2)$$

where Pe is that part of the rainfall that can be utilized from the crops and it is called effective rain, Gw is the contribution of underground water and SM is the water that is stored in the area of the roots in the beginning of the germinative period and can be used by the crops. In the present study, the term Gw was assumed to be equal to zero, because the water table level in the plain of Thessaly is very low. It was also assumed that the soil moisture during seeding and harvest was in the same level, therefore the term SM was received equal to zero, too. Outside the net water requirements that should be covered with irrigation, there is need for additional quantities of water for the wastewater of salts that is assembled in the area of the roots as a consequence of irrigation. In this study it is considered that the needed wastewater of salts takes place after the harvest.

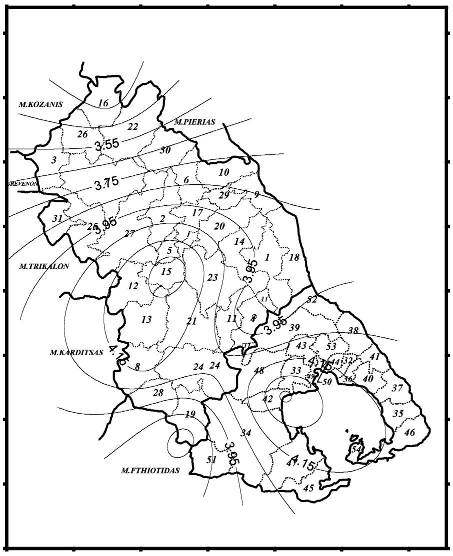

Figure 1. Isoevapotranspiration curves for May.

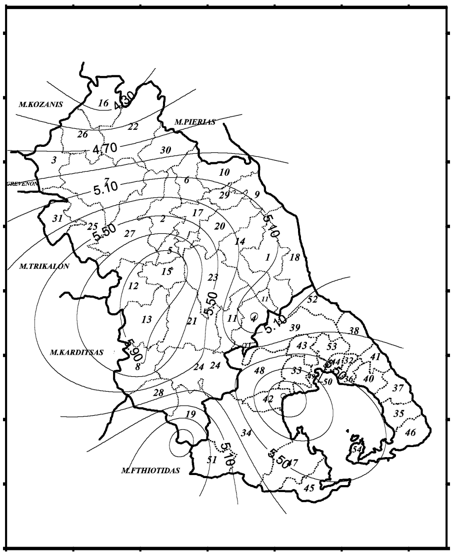

Figure 2. Isoevapotranspiration curves for June.

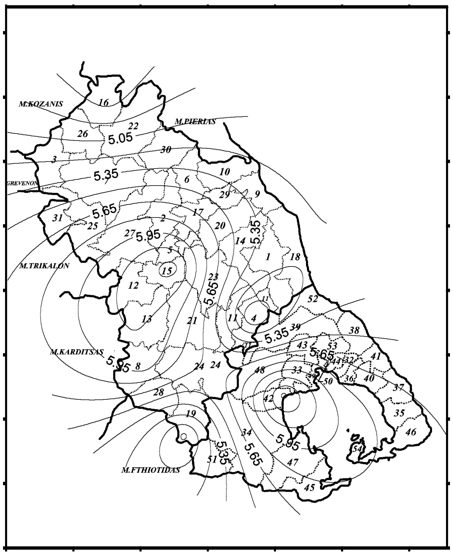

Figure 3. Isoevapotranspiration curves for July.

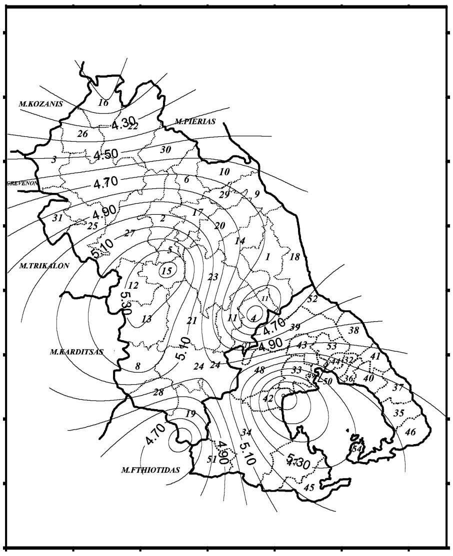

Figure 4. Isoevapotranspiration curves for August.

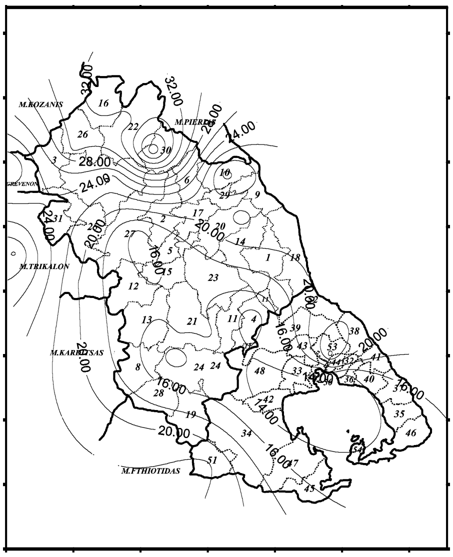

Figure 5. Isohyetial curves for July.

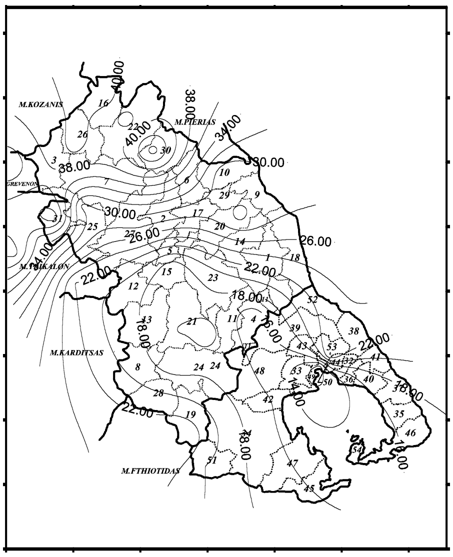

Figure 6. Isohyetial curves for August.

LEGEND

1 M.AGIA
2 M.ABELONAS
3 M.ADIHASION
4 M.ARMENIO
5 M.GIANOULI
6 M.GONI
7 M.ELASSONA
8 M.ENIPEAS
9 M.EVRIMENON
10 M.KATO OLIMPOS
11 M.KILELER
12 M.KILADA
13 M.KRANONAS
14 M.LAKERIA
15 M.LARISSA
16 M.LIVADI
17 M.MAKRIHORI
18 M.MELIVIA
19 M.NARTHAKI
20 M.MESSON
21 M.NIKEA
22 M.OLIMPOS
23 M.PLATIKAMPOS
24 M.POLIDAMADAS
25 M.POTAMIA
26 M.SARADAPORO
27 M.TIRNAVOS
28 M.FARSALA
29 M.AMPELAKIA
30 M.KARIA
31 M.VERDIKOUSA
32 M. AGRIA
33 M. ESONIA
34 M. ALMIROS
35 M. ARGALASTI
36 M. ARTEMIDOS
37 M. AFETON
38 M. ZAGORA
39 M. KARLA
40 M. MILIES
41 M. MOURESI
42 M. NEW ANCHIALOS
43 M. NEA IONIA
44 M. PORTARIA
45 M. PTELEOS
46 M SIPIADA
47 M. SOURPI
48 M. FERON
49 M. VOLOS
50 M. IOLKOS
51 M. ANAVRA
52 M. KERAMIDI
53 M. MAKRINITSA
54 M. TRIKERI

Consequently, for the calculation of net water requirements, we calculate the difference crop evapotranspiration ETc of crops minus the effective rainfall Pe. The effective rainfall was calculated with the method of USDA (Soil Conservation Service) as follows

$$P_e = P_{tot}\,(125\text{-}0.2\ Ptot)/125 \quad for\ P_{tot} < 250mm$$

$$P_e = 125 + 0.1\ P_{tot} \qquad for\ P_{tot} > 250mm$$

where P_{tot} is the total rainfall.

Finally, the total irrigation water requirements $I_{n\ tot}$ of crops were found for the whole irrigation period according to the statistics of crops of the year 2001 of the Administration of Land Improvements of the Prefectures of Larissa and Magnesia.

The calculation of the total irrigation water requirements for each crop and for the whole irrigation period in each Municipality, $I_{n\ tot}$, was done by multiplying the net water requirements I_n of the crops with the corresponding areas that they cover. The calculations were accomplished by using the Papazaferiou's (1999) crop coefficient, Kc, in the climatic conditions of Greece for cotton, sugar beets, maize and vine. The coefficients for the rest of the crops were taken from Allen et al. (1996). The mean crop coefficients of trees, as they are given by Allen et al. (1996), coincide with the corresponding mean crop coefficients that were defined by Papazaferiou (1999) in the climatic conditions of Greece. The lengths and dates of growth stages were taken from Papazaferiou (1999) and from farmers' diaries.

4. RESULTS AND DISCUSSION

The values of average total crop evapotranspiration ET_c (mm/period) for each crop for the Prefectures of Larissa and Magnesia with the use of the mean crop coefficients that are given by Allen et al. (1996) and by Papazaferiou (1999) as they are defined in the climatic conditions of Greece, are presented in Figure 7, where it is obvious that the sugar beets present the higher crop evapotranspiration because of higher crop coefficient. Next other crops follow such as alfalfa, trees, cotton, maize, tobacco, vegetables, vines, cucumber family and lastly the cereals.

The crop evapotranspiration ET_c that was found with the use of the mean crop coefficients, Kc, as they are given by Allen et al. (1996), is higher than the one found with the use of the mean crop coefficients, Kc, as they were defined by Papazaferiou (1999) in the climatic conditions of Greece at 2.4% for the cotton, 16.4% for the sugar beets, 3.7% for the maize and 18.3% for the vine. For the two Prefectures, the volumes of water that correspond to these percentages are 13,535,000m^3 for the cotton, 8,528,500m^3 for the sugar beets, 1,784,000m^3 for the maize and 1,943,000m^3 for the vine. Totally, for these crops 25,790,000m^3 less water is required when crop evapotranspiration is calculated with the use of the mean crop coefficients that were defined by Papazaferiou (1999).

In Figure 8, there is a presentation of the total irrigation water requirements for each crop and for the whole irrigation period in entire the Prefectures of Larissa and Magnesia.

The total crop evapotranspiration of the crops of the Prefectures is 929,493,000m^3, while the volume of rainfall is 231,500,000m^3 and constitutes the 24.9% of total evapotranspiration. The rest 75.1% (698,000,000m^3) that is the total water requirements should be covered with irrigation.

In percentages, the volumes of water of irrigation that crops consume are: Cotton 60.73%, Sugar beets 4.82%, Alfalfa 3.45%, Tobacco 1.72%, Maize 5.08%, Trees 16.22%, Vines 0.78%, Vegetables 3.71%, Cucumber Family 0.70% and Cereals 2.76%. The highest volumes of water are consumed by the crop of cotton, because it covers the largest area and it is one of the most demanding in irrigation water crops.

In Figure 9, there is a presentation of the total irrigation water requirements for the whole irrigation period in each Municipality, I_{ntot} of the Prefectures of Larissa and Magnesia. According to the figures, the Municipalities which have the higher water requirements are those that have the most irrigated areas with the more demanding in irrigation water crops such as cotton, sugar beets, alfalfa, maize and trees.

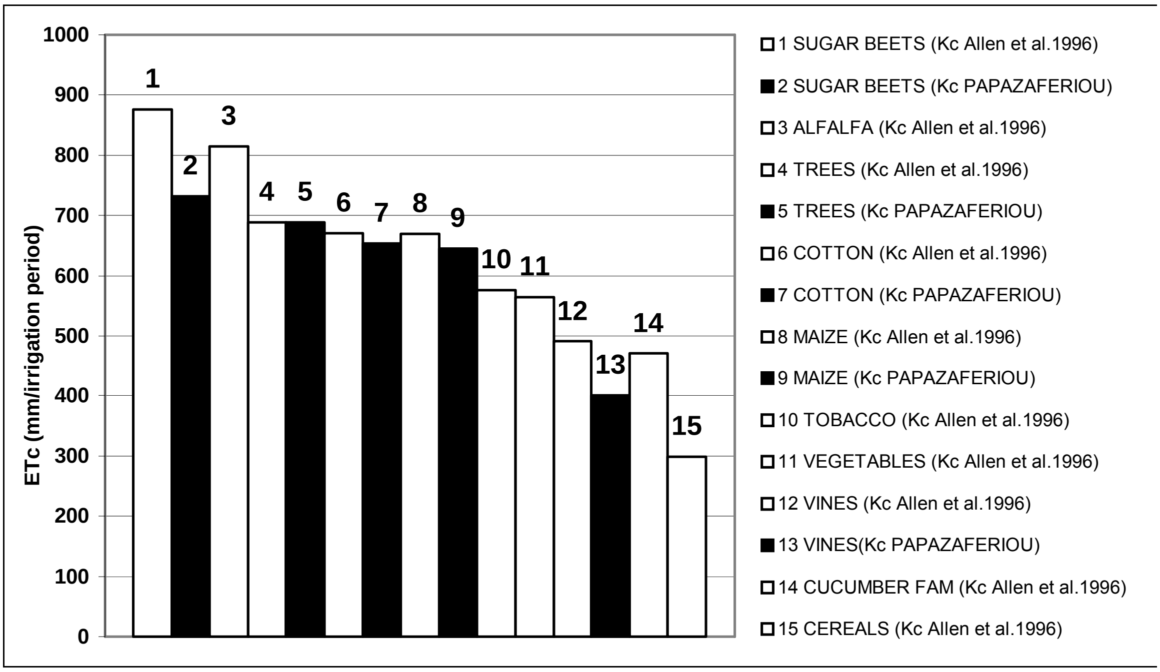

Figure 7. Crop evapotranspiration ETc (mm/period) for each crop for the Prefectures of Larissa and Magnesia.

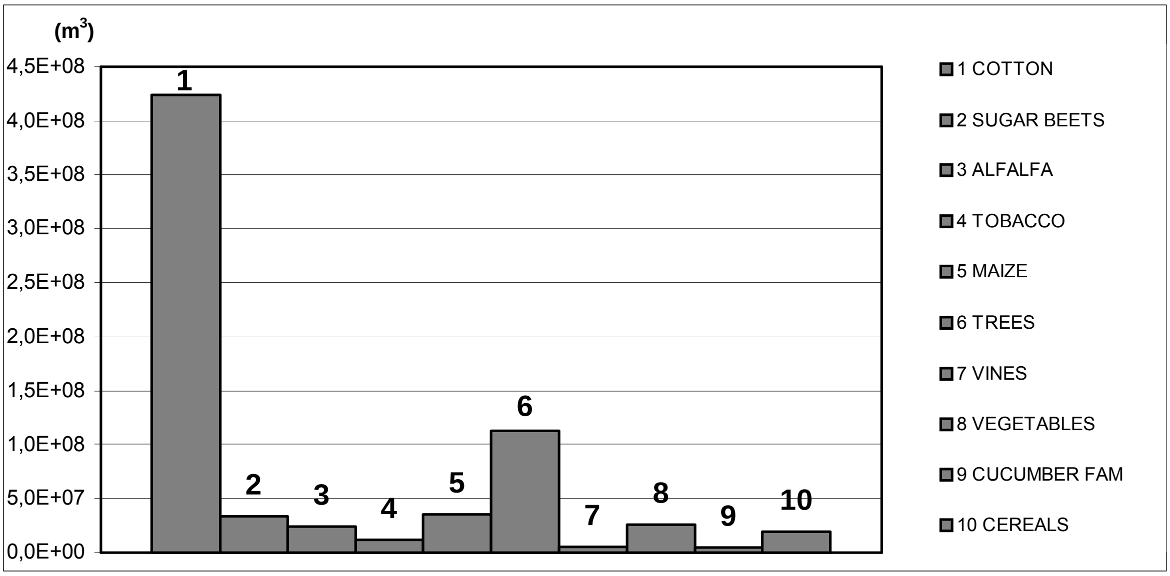

Figure 8. Total irrigation water requirements for each crop and for the whole irrigation period in entire the Prefectures of Larissa and Magnesia, $I_{n\ tot}$ (m^3).

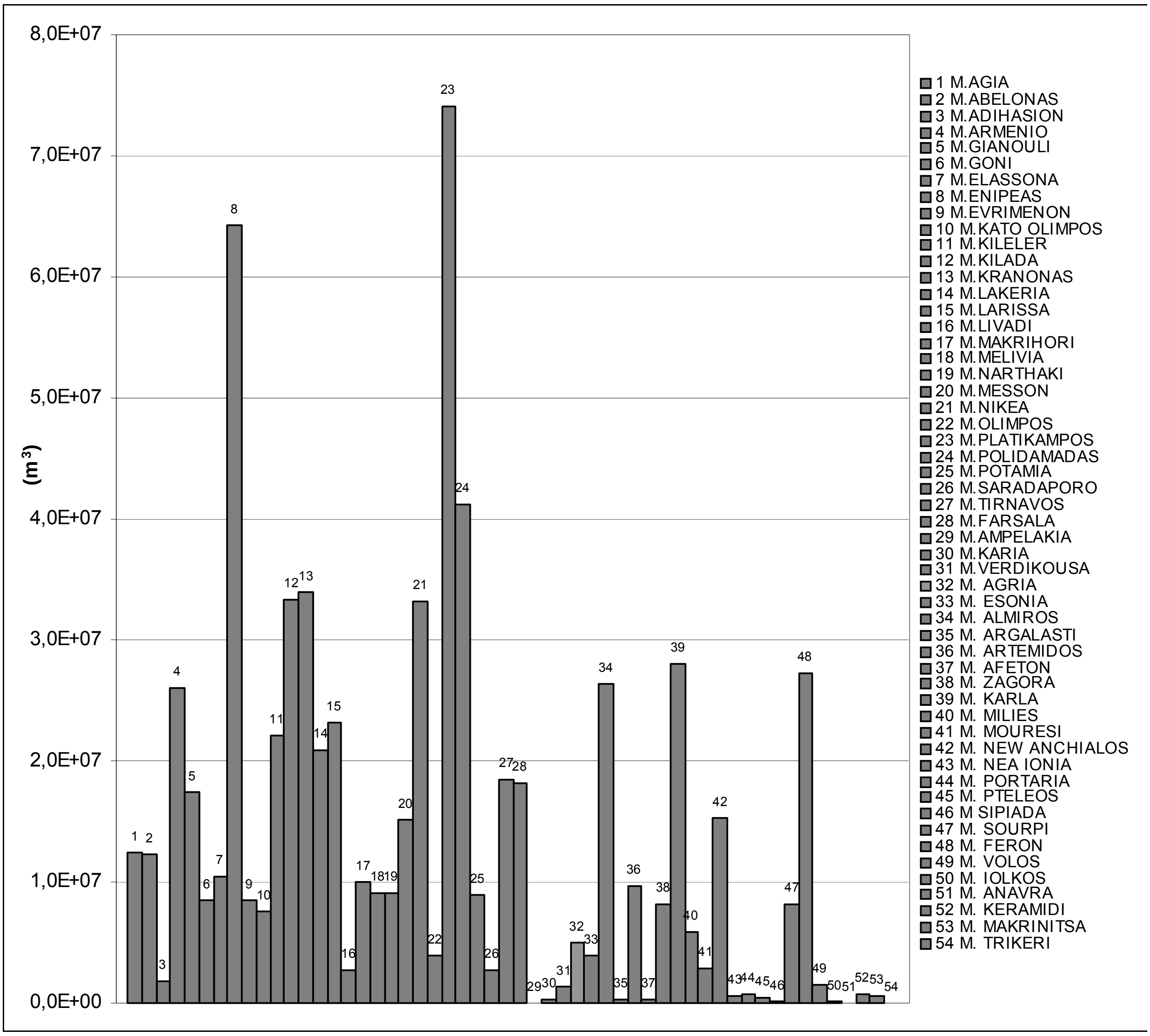

Figure 9. Total irrigation water requirements for the whole irrigation period in each Municipality, I_{ntot} (m^3), of the Prefectures of Larissa and Magnesia.

5. CONCLUSIONS

A mapping of reference crop evapotranspiration and rainfall was obtained by using meteorological data for a period of 22 years from 7 meteorological stations of the Prefectures Larissa and Magnesia of Central Greece. With the aid of these maps, crop evapotranspiration and net water requirements were computed for each crop in the Municipalities of the Prefectures for the whole irrigation period.

The percentage of the total crop evapotranspiration of the crops of the two Prefectures covered by rainfall is 24.9%, while the rest 75.1% should be covered by irrigation.

The total irrigation water requirements of crops during the irrigation period of the year 2001 for the 147,299 hectares of irrigated areas of the Prefectures of Larissa and Magnesia are 698,000,000m^3 with average 4,739m^3/hectare.

The Municipalities of Platikampos and Enipeas for the Prefecture of Larissa have the highest water requirements, because they have the most irrigated areas with the most demanding in irrigation water crops such us cotton, sugar beets, alfalfa, maize and trees. For the same reasons the Municipalities of Karla, Feron and Almiros for the Prefecture of Magnesia have the highest water demands.

The highest volume of water is consumed by the crop of cotton, because it covers the largest area and it is one of the most demanding in irrigation water crops.

In the present study the reference crop evapotranspiration with the use of FAO Penman-Monteith method, was found lower by 18.5% from the reference crop evapotranspiration that was found with the use of modified method of Penman.

The above study can be used by the researchers as well as the corresponding administrations of the Prefectures of Larissa and Magnesia that deal with the construction of irrigation networks, tanks and dams to estimate the water requirements of crops for the areas of interest with the help of the given maps. Also, it can contribute to the proper function of existing irrigation networks and more generally in the rational use and management of water recourses. The small partial division of the Prefectures at Municipalities enhances the accuracy and the easiness of the above calculations.

The process of calculation of reference crop evapotranspiration is dynamic, that is to say that the values should be updated by entering new climatic data from the existing or new meteorological stations that are installed. It is realised that the number of meteorological stations is small and their distribution in the area is not of the best.

REFERENCES

Allen, R. G., Jensen, M. E., Wright, J. L., and Burman, R. D., 1989. Operational estimates of reference evaportaspiration. Agron. J.; 81: 650-662.

Allen, R.G., Smith, M., Perrier, A., and Pereira, L. S., 1994. An update for the definition of reference evapotranspiration. ICID Bulletin.

Allen, R.G., Smith, M., Pereira, L. S. and Pruitt, W. O., 1996. Proposed revision to the FAO procedure for estimating crop water requirements. Proc. of the 2nd Int. Symp. on Irrigation of Horticultural Crops, K. S. Hartzoulakis (ed.), Vol. 1, p. 17-33.

Allen, R.G., Pereira, L. S., Raes, D. and Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, Rome.

Brutsaert, W. H., 1975. Comments of surface roughness parameters and the height of dense vegetation. J. Meteoral. Soc. Japan; 53: 96-97.

Katsoulas N., Baille A., Kittas C., 2001. Effect of misting on transpiration and conductances of a greenhouse rose canopy. Agricultural and Forest Meteorology; 106: 233-247.

Kittas C., Baille A., Katsoulas N., 1999. Transpiration and canopy resistance of greenhouses soilless roses in Greece. Measurements and modelling. Acta Horticulturae; 507: 61-68.

Kougoulos, K., 1979. The problems of Thessaly. Minutes of convention for the Water Resources of Thessaly, T.E.E. Larissa.

Monteith, J. L., 1965. Evaporation and Environment. 19th Symposia of the Society for Experimental Biology, University Press, Cambridge; 19: 205-234.

Monteith, J. L., 1981. Evaporation and surface temperature. Quart. J. Roy. Meteorol. Soc.; 107: 1-27.

Papazaferiou, Z. G., 1999. Crop water requirements. Ziti Publications, Thessaloniki.

Papazaferiou, Z. G., 2000. “National strategy for the water resources”. Convention-Workshop, Agriculture & Environment, February, Athens.

Patmanidis, J., 1979. Thessaly requirements for water of irrigation and animal water supply. Minutes of convention for the Water Resources of Thessaly, T.E.E. Larissa.

Pereira, L. S. and Smith, M., 1989. Proposed procedures for revision of guidelines for predicting crop water requirements. Land and Water Use Div., FAO Rome, 36p.

Plate, E. J., 1971. Aerodynamic characteristics of atmospheric boundary layers. U.S. Atomic Energy Comm., Critical Review Series, TID-25465, 190p.

Sakellariou-Makrantonaki, M. S., 1996. Total crop water requirements of the Thessalian plain, Hydrotechnica, Vol. 6, p. 62-77.

SRTS (Scientific Research and Technology Service), 1980. Programme for development and adaptation of estimating methods of water resources of Greece. Technical Report, No 4, 88 p.

Szeicz, G. and Long, I. F., 1969. Surface resistance of crop canopies. Water resour. Res.; 5: 622-633.

Smith, M., Allen, R. G., Monteith, J. L., Perrier, A., Pereira, L. and Segeren, A., 1991. Report of the expert consultation on procedures for revision of FAO guidelines for prediction of crop water requirements. UN-FAO, Rome, Italy, 54 p.

U.S.D.A., Soil conservation service, 1970. Irrigation water requirements. Tech. Release No 21,92-94.

Hatzilakos, G., 1979. Estimation of the crop water requirements of Thessaly. Minutes of convention for the Water Resources of Thessaly, T.E.E. Larissa.