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A HANDY IRRIGATION MANAGEMENT METHOD THROUGH METEOROLOGICAL DATA. CASE STUDY IN N. GREECE

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ABSTRACT

Crop irrigation, especially in irrigation networks, often consumes larger quantities of irrigation water than necessary since most of the times irrigation is carried out empirically and not based on actual crop requirements. The aim of this work is the management of irrigation water though the use of meteorological data. This approach was utilized for the first time in Greece and applied in a pilot area of about 6,000 ha at the Local Organization of Land Reclamation in Nigrita. The method is based on accurate calculation of daily evapotranspiration of the common cultivations at the area (maize, cotton, alfalfa), using meteorological data. Thus irrigation is organized based on actual water consumption of the crops ensuring the qualitative and quantitative characteristics of their products.

Keywords: crop water requirements, meteorological data, water management, irrigation.

1. Introduction

Irrigation advisory services can significantly help farmers in adopting new technologies to increase water use efficiency, while minimizing environmental risks and contributing to sustainable agriculture. Management of irrigation water through the development of mathematical models and consulting services, as a solution to the problem of water resources availability, is revealed by the widespread involvement of many universities and research institutions around the world.

In Australia, the C*ommonwealth Scientific and Industrial Research Organisation (CSIRO)* Land and Water has developed a group of models called SWAGMAN (Salt Water and Groundwater MANagement). The individual models of SWAGMAN are SWAGSIM (Salt Water and Groundwater SIMulation) (Prathapar *et al.*, 1995), SWAGMAN Destiny (Meyer *et al.*, 1996) and SWAGMAN Farm (Khan *et al.*, 2002). Of these, SWAGMAN Farm is a combination model of water balance and salt balance in a field and is used as an educational tool and also as a management tool by different body officials and producers in the Coleambally area of South Australia.

In Canada, the irrigation advisory agencies have been established mainly in the western part of the country. Traditionally in this country advisory service for irrigation was the responsibility of the public sector, but recently an increasing involvement of private entities is observed. In the area of Manitoba, irrigation is the farmers' responsibility and is carried out through the growing use of measuring devices for soil moisture. In the area of Alberta, the local government trains employees of private companies and groups of farmers on the use of a model (Alberta Irrigation Management Model - AIMM), which was developed and designed specifically for the climate of the region (Tollefson *et al.*, 2002).

In Italy, the demand for irrigation advisory services increased during the 1990's. For this purpose, the regional agency ARSIA (Agenzia Regionale per lo Sviluppo el'Innovazione Agricolo-forestale) in collaboration with the universities of Pisa and Florence developed a methodology for irrigation scheduling of about 50 fields informing farmers by using mobile messages and web pages (Giannini and Bagnoni, 2002).

In the Spanish region of Castilla-La Mancha, the State Institute ITAP (Instituto Técnico Agronómico Provincial de Albacete), which was established in 1986, provides data on irrigation water demand for the regional crops. The irrigation water demand is obtained by the use of three lysimeters (one of them is exclusively used for the study of vineyard), the equation of Penman - Monteith and meteorological data (Montoro Rodríquez *et al.*, 2002).

In U.S.A. a variety of government agencies, consulting companies and other organizations contribute to the irrigation scheduling. The most famous organization CIMIS (California Irrigation Management Information System) was founded in 1980 by a joint action of the Water Resources (CDWR) agency and the University of California. The CIMIS provides data to farmers for the daily evapotranspiration, through a network of meteorological stations, remote sensing and a Geographical Information System. All these data are used for the estimation of irrigation water demand and for irrigation scheduling of local cultivations.

In Greece there is a lack of similar actions. A pilot system of tele-information for farmers at two small areas in Crete was introduced in 2005. For each area a database was created in Geographical Information System (GIS) environment containing information on soil properties, specifically: on the slope, soil texture, specific weight, field capacity, permanent wilting point, porosity and infiltration rate. Based on these data, information for the irrigation dose is provided to farmers through a simple call during which they supply the system with the necessary information: location of cultivation, kind of cultivation, soil type and date of last irrigation (Chartzoulakis, 2005).

The aim of this paper is to present a methodology towards rationalisation of water resources management through the proper irrigation of crops by using meteorological data. Proper irrigation aims at achieving qualitative and quantitative yield. The methodology was developed for a pilot area of about 6,000 ha, which is located at the Local Organization of Land Reclamation (L.O.L.R.) in Nigrita, at Central Macedonia Region in northern Greece. The farmers were instructed to sufficiently irrigate at the beginning of the irrigation period in order to reach field capacity, based on their previous experience. Using data provided from meteorological stations, daily evapotranspiration is calculated for each of the common crops of the area (maize, cotton, alfalfa). Farmers are informed of the crop water requirements of each field via a dedicated web page, when they decide empirically to irrigate. Thus, irrigation is organized based on the actual consumption of crop water, ensuring the qualitative and quantitative yield.

2. Theory

Daily net crop water requirements (In) are calculated from the following equation (Ritzema 1994):

$$In = ET_c - (Pe + SM + GW) \quad (1)$$

where ET_c is the crop evapotranspiration in mm d^{-1}, Pe is the effective precipitation in mm d^{-1}, SM is the change of soil moisture content in root zone between start and end of the cultivation period in mm d^{-1} and GW represents the contribution of phreatic groundwater that reaches the root zone due to capillary forces in mm d^{-1}.

Crop evapotranspiration (ET_c) is calculated as:

$$ET_c = ET_r \; kc \tag{2}$$

where kc is the crop coefficient and ET_r is the reference evapotranspiration in mm d^{-1} that is estimated using the modified Penman-Monteith by FAO-56 (Allen *et al.*, 1998):

$$ET_r = \frac{0.408(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \tag{3}$$

where R_n is the net radiation at the crop surface in $MJm^{-2}d^{-1}$, G is the soil heat flux in $MJm^{-2}d^{-1}$, T is the mean daily air temperature at 2 m height in °C, u_2 is the wind speed at 2 m height in ms^{-1}, e_s is the saturation vapour pressure in kPa, e_a is the actual vapour pressure in kPa, e_s-e_a is the saturation vapour pressure deficit in kPa, Δ is the slope vapour pressure curve in kPa^oC^{-1} and γ is the psychrometric constant in $kPa°C^{-1}$.

Effective precipitation (Pe), as required in eq. 1, is calculated using the following USDA Soil Conservation Service equation (USDA 1970):

$$Pe = f(D) \; (1.25 \; Pt^{0.824} - 2.93) \; 10^{0.000955 \; ETc} \tag{4}$$

where Pt is total precipitation in mm d^{-1} and D is the decline allowed in soil moisture content until the next irrigation dose is applied. Function f(D) is an adaptation factor that equals 1 when D = 75 mm, whilst for every other value of D f(D) is calculated as:

$$f(D) = 0.53 + 0.0116D - 8.94E\text{-}05D^2 + 2.32E\text{-}07D^3 \tag{5}$$

3. Material and methods

The pilot area (6,000 ha), where the methodology was applied, was the L.O.L.R. in Nigrita, at Central Macedonia Region in northern Greece. Three meteorological stations were installed for recording hourly step values of: depth and duration of precipitation, maximum, minimum and mean air temperature, maximum, minimum and mean relative humidity, wind speed and direction and sunshine duration. Using the collected data from these stations the daily crop evapotranspiration (eq. 2) is calculated through specific software, which was developed for this application. Since crop coefficient values were not available for the pilot area, estimates were made after consulting the literature (Allen *et al.*, 1998; Papazafiriou 1999; Paltineanu *et al.*, 1999; Panoras *et al.*, 2001), and these are presented at Table 3. The daily effective precipitation (eq. 4) and the daily net crop water requirements (eq. 1) are also calculated with the same software. Soil moisture change in the root zone between start and end of the cultivation period is assumed to be negligible, since it never exceeded field capacity during irrigation period as shown in Figures 1 to 6. So it is not accounted for the calculation of the daily net crop water requirements. Also since observations in the area suggest that the contribution of the ground water level is too low to affect the crop rooting zone, the contribution of phreatic groundwater is omitted (Van Hoorn, 1979). Finally adding to the net crop water requirements a percentage of 15% to account for inaccuracies to input data, the daily water need for each crop is calculated.

As already stated, farmers were instructed to irrigate at the beginning of the irrigation period sufficiently in order to approach field capacity based on their previous experience. It is therefore assumed that at the beginning of each irrigation period the soil moisture is near field capacity and the daily water requirement of each crop is calculated as above, hence the necessary water volume for restoring the soil moisture to field capacity is recommended to the farmer. This way the farmer irrigates according to the water requirements of each crop. Thus, each one of the cultivations receives throughout the irrigation period, the necessary amount of water required for optimum growth, without wasting irrigation water.

The methodology was applied for the cultivation periods of 2007 and 2008. Two fields of 1 ha each from each cultivation (maize, cotton, alfalfa) were selected in order to test the methodology. Three of them were used as experimental and the other three as control. At the beginning of the cultivation period the main soil properties of each field were measured (e.g. field capacity, permanent wilting point etc). During the irrigation period measurements of soil moisture content were carried out twice a week at the experimental fields (Figures 1 – 6). Volumetric soil moisture content was measured by responses to changes in the dielectric constant of the soil using Diviner 2000 device of SENTEK. Soil moisture was measured at 10 cm intervals up to 60 cm depth and at three different points of each field. Finally, the cultivation yield and the applied water volume were measured in all fields in order to evaluate and validate the methodology. The yield was determined by weighting the total product of each field and the irrigation water was measured with hydrometers during applications.

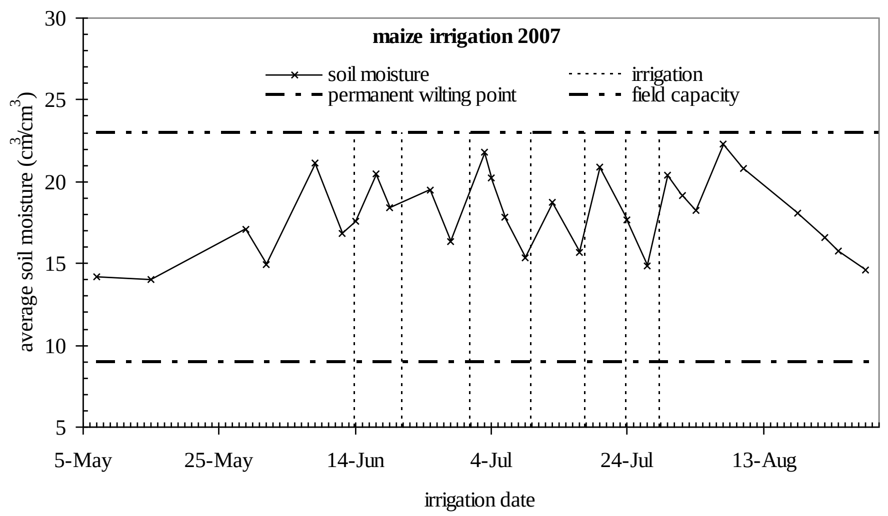

Figure 1. Maize irrigation at cultivation period of year 2007

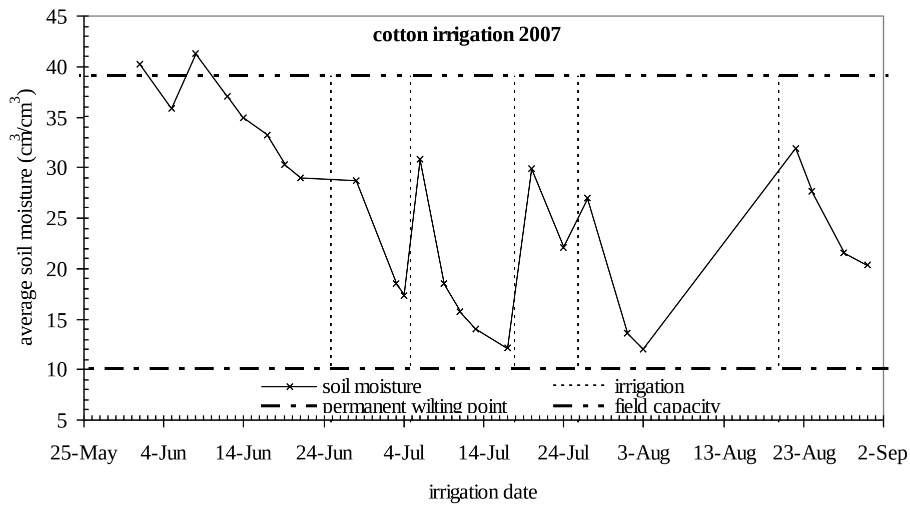

Figure 2. Cotton irrigation at cultivation period of year 2007

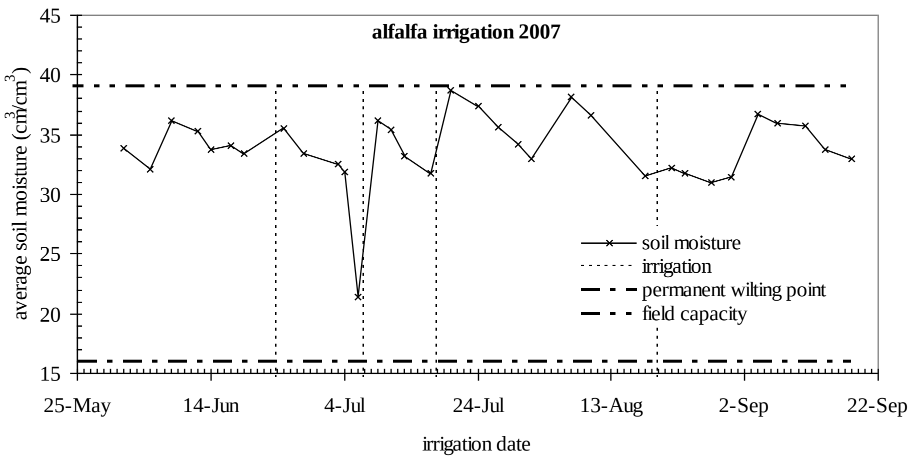

Figure 3. Alfalfa irrigation at cultivation period of year 2007

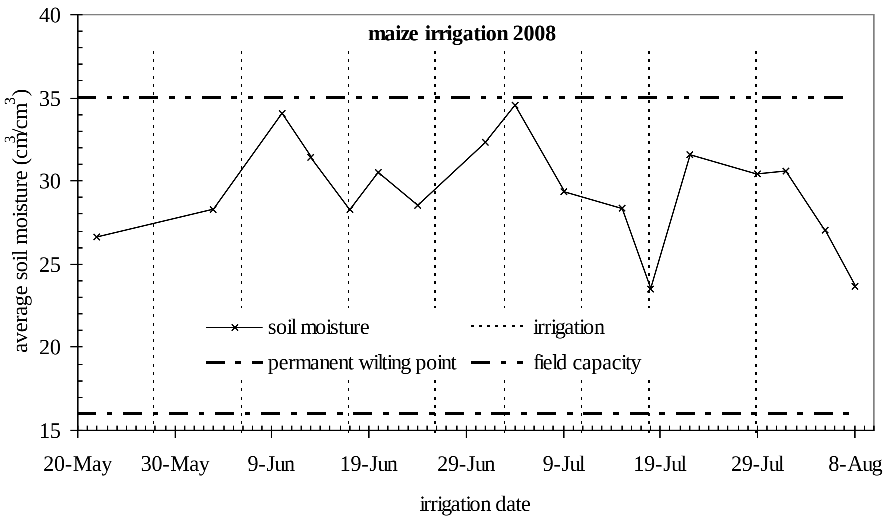

Figure 4. Maize irrigation at cultivation period of year 2008

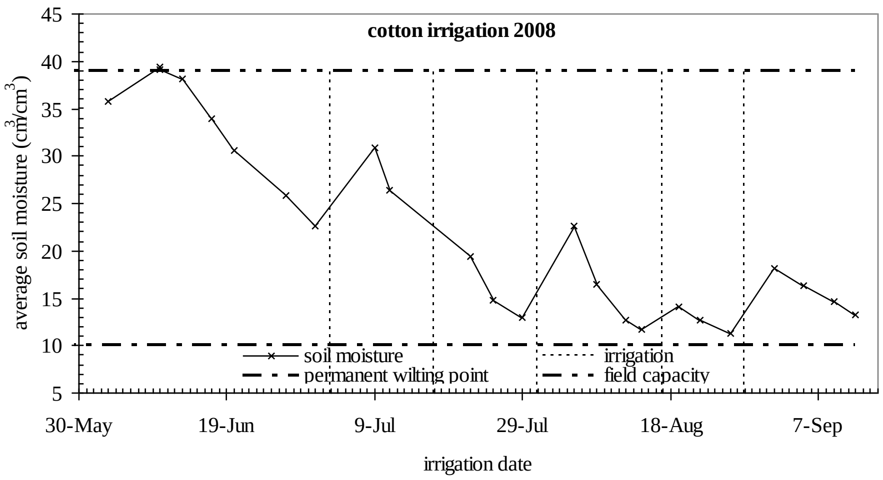

Figure 5. Cotton irrigation at cultivation period of year 2008

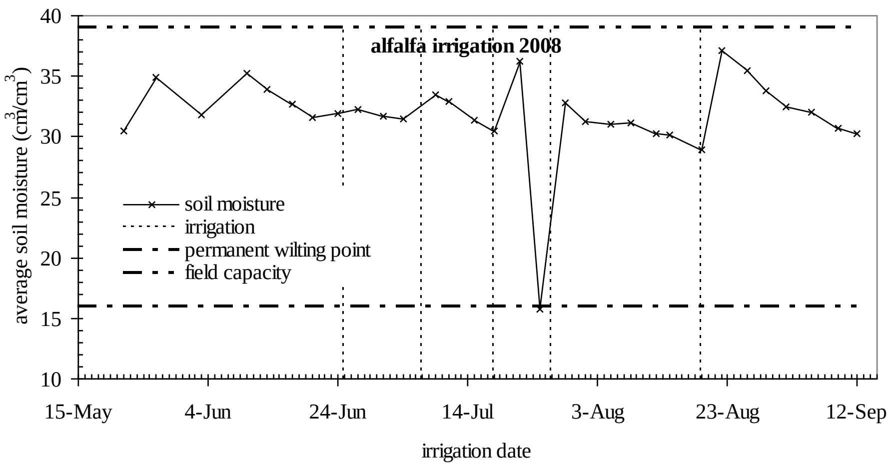

Figure 6. Alfalfa irrigation at cultivation period of year 2008

4. Results – Discussion

The evaluation and validation of the methodology was carried out by comparing the yield between the experimental fields and the corresponding controls taking into account the volume of water utilized.

Table 1 shows the volumes of irrigation water applied to the experimental fields and the corresponding controls for both cultivation periods, and it also shows the effective precipitation, as calculated by eq. 4. Finally, the achieved water use reduction is shown in Table 1, as calculated by the comparison of the water volumes used in the experimental and the control fields. Table 2 shows the cultivation yield in Kg ha^{-1} of each crop in the experimental fields and controls. Additionally in the same table the ratio between the amounts of yield and total water volume that was used per year in Kg m^{-3} is presented. We notice that there is an improvement of yield/water in all cases with the lower one for cotton. This is attributed to the fact that cotton production is more sensitive to the deviation of total water volume used.

Table 1. Irrigation water, effective precipitation and water use reduction

Cultivation	Experimental $m^3 ha^{-1}$	Control $m^3 ha^{-1}$	Eff. Precipitation $m^3 ha^{-1}$	Water Use Reduction %
Cultivation period 2007				
Maize	3590	5000	800	39
Alfalfa	3130	3800	830	21
Cotton	2700	3200	700	19
Cultivation period 2008				
Maize	4050	7050	640	74
Alfalfa	2790	3620	440	30
Cotton	4570	5500	510	20

Table 2. Cultivation yield

Cultivation	Experimental		Control	
	Kg ha^{-1}	Kg m^{-3}	Kg ha^{-1}	Kg m^{-3}
Cultivation period 2007				
Maize	14780	3.36	13930	2.40
Alfalfa	13500	3.41	12700	2.74
Cotton	4000	1.18	4000	1.03
Cultivation period 2008				
Maize	13340	2.84	13480	1.75
Alfalfa	14600	4.52	13650	3.36
Cotton	3700	0.72	3400	0.56

Finally, since soil moisture content values were monitored, the crop coefficient was calculated (Allen *et al.*, 1998) after the end of the experiment in order to compare the literature values with actual ones. The results are presented in Table 3 and illustrated in Figures 7 – 9.

Table 3. Values of literature crop coefficients and experimental

	maize			cotton			alfalfa		
	kc ini	kc mid	kc end	kc ini	kc mid	kc end	kc ini	kc mid	kc end
experiment	0.47	1.00	0.58	0.35	1.19	0.62	0.61	0.94	0.89
literature	0.50	1.06	0.60	0.35	1.20	0.65	0.50	1.15	1.10

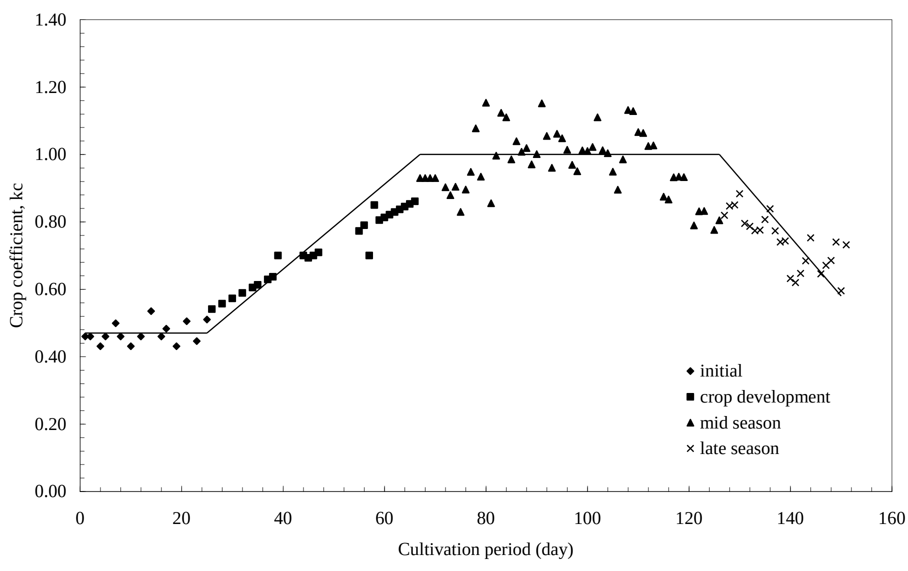

Figure 7. Crop coefficient curve for maize

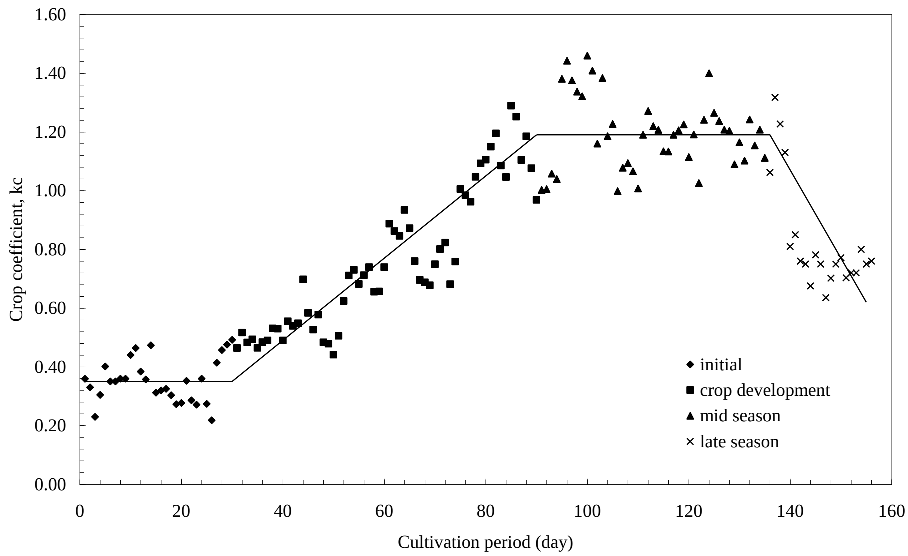

Figure 8. Crop coefficient curve for cotton

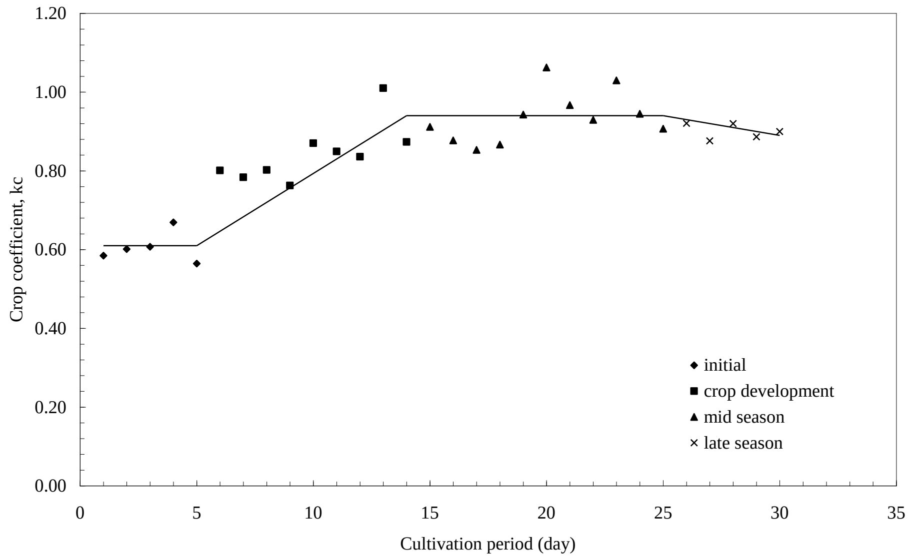

Figure 9. Crop coefficient curve for alfalfa

5. Conclusions

This irrigation methodology utilizing meteorological data was applied for the first time in Greece at Nigritas' network irrigation system for the common cultivations of the area. Application of this methodology shows that a saving of irrigation water consumption from 19 to 74% can be achieved depending on the crop, compared to the control consumption, as shown in Table 1. The higher water savings were observed in maize, which happens to be the most water demanding cultivation.

There was no significant variance in yield and product quality between the experimental fields and controls as it may be easily deduced from Table 2. Crop coefficients that were calculated experimentally were very close to the ones selected from the literature for the application. The only exception lies with the calculated alfalfa crop coefficients that exhibit a deviation of about 20% from literature values. This deviation is attributed to either the cultivated variety, or the methodological approach adopted, i.e. calculation of a mean crop coefficient value out of the five harvests within the same irrigation period.

The main issues for scheduling irrigation are two: a) the date that the cultivation should be irrigated (when?) and b) the irrigation dose (how much?). The methodology, described above, answers the second question by obtaining information on the date from the farmers, who select the irrigation date empirically and occasionally on the basis of water availability on the collective irrigation network that normally operates on a rotation system. As shown at Figures 1-6, the farmers select the date of irrigation in almost a correct way, on low soil moisture content. Thus, the methodology informs the farmers on the necessary amount of water required for each one of the cultivations for optimum growth, without wasting irrigation water, leading to rational irrigation management.

The proposed methodology does not require extensive or detailed soil measurements since it relies on simple mass balance equations and meteorological data which are easily obtainable. It is a handy methodology that can be easily applied giving very good results with very low cost. The only drawback of the method is that the farmers should have enough experience in order to administer during the first irrigation enough water to approach field capacity.

Overall, the proposed methodology is based on simple yet robust data that are easy to collect and utilise through a straight forward low investment cost infrastructure. The cost benefit ratio of the methodology is deemed extremely favorable on the basis of the water savings achieved. These may be translated to environmental protection (used water volumes reduction, reduction of potential pollution through runoff and leaching, reduction of energy consumption used up for water abstraction-transportation), and also savings on energy bills due to the reduced water volumes used.

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